DESIGN OF FREE FLOWING GRANULAR DRAINS FOR GROUNDWATER CONTAINMENT APPLICATIONS

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Abstract

Many geoenvironmental applications make use of granular drainage layers. Design guidelines for these drains recommend a granular soil that provides for filtration of the adjacent base soil. Filtration criteria have been developed through laboratory studies in which fine soils under a concentrated gradient of water are protected from erosion by a filter soil. The primary objective in these studies has been the geotechnical stability of earth-fill structures, while drainage was a secondary consideration. Granular drainage layers have therefore been constructed using fine sand. The subsequent migration of fine soil into these drains has resulted in significant loss in permeability.

The main research objective was to develop design criteria for granular drains to be used for long term operation in environmental applications. The secondary objective was to investigate the relationships between grain size distribution of drain materials and clogging by fines. This was done through a laboratory study where changes in permeability were measured in granular soils infiltrated with fines. Lastly, the effect of salinity on fines deposition was also investigated. The hypothesis of the current study is that coarser granular drains minimize the impact of clogging and provides a better alternative to traditional drain designs for long term environmental applications.

The laboratory study was performed with three granular drainage soils: a French Drain sand designed using the traditional filter design method, a coarser uniform sand, and a coarser graded sand with approximately 40% gravel sized particles. Three fine soils were used to infiltrate the drainage soils; however, their particle size distributions were not significantly different from one another. The results indicate that the permeability of all three drainage soils could be reduced by

approximately one order of magnitude with continuous flow of a high concentration of fines (5 g/L). The permeabilities of the sands were reduced to a lesser extent with a lower concentration of fines. Permeabilities of the graded soils decreased more slowly with a lower concentration of fines, when considering pore volumes of flow. However, the rate of permeability decrease was ultimately influenced by the amount of fines delivered to the sample. A lower concentration of fines did not significantly slow the rate of permeability reduction in the uniform sand. All three sands retained a similar mass of fines (samples were split and fines content measured following each test). Salinity in the pore water did not significantly affect deposition, likely due to the fact that the fines contained a small amount of clay sized particles.

When considering that all three drainage soils became clogged with fines during the tests, the coarse soils maintained a relatively high permeability due to the fact that their pre-test permeabilities were high. This information, along with the results from the literature review, has led to the development of recommended new design criteria for granular drains to be used for long-term geoenvironmental applications. Test results from an earlier study found that dispersive soils subject to high gradients can be successfully protected by a filter coarser than the coarse graded soil used in the current study. It therefore follows that a granular soil intended for groundwater collection applications can be made to be coarser than the current accepted practice. A proposed granular drain design band is presented in the current study.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOGRAPHS

APPENDICES

CHAPTER 1 INTRODUCTION

1.1 Subject

The control of groundwater flow is a major component in the design of geotechnical structures and geoenvironmental systems. One method of groundwater control is the use of soil filters and drainage layers. The primary purpose of the soil filter is to ensure the stability of the adjacent soil (known as the base soil), while allowing for pore pressure dissipation. Many earth-fill dams have failed due primarily or partially to inadequate filter design. Thus, design guidelines for soil filters stem from extensive laboratory studies, focused on the prevention of erosion of dam core materials due to a concentrated leak. Current practice in soil filter design is based on a comparison of particle sizes in the base soil to that of the filter soil.

There are many design applications where filtration and water drainage are both desired. The design guidelines have been developed with drainage criteria as a secondary consideration. This may be detrimental to granular drainage layers, if the soil loses a significant portion of its permeability during its design life. The specific area of interest in this study considers granular drains installed around potash mine tailings storage areas.

1.2 Need

Soil filter design guidelines are currently being utilized for geoenvironmental applications such as landfill leachate collection systems and seepage collection systems surrounding contaminated sites. It is becoming increasingly common to install engineered granular drainage systems. These systems are expected to retain sufficient permeability in order to continuously collect large volumes of water. In some cases, the chemical and biological attributes of the flowing pore water may create erosion and deposition conditions significantly different than those used in the development of the filter design guidelines. The primary objective in past filter design studies has been the geotechnical stability of earth-fill structures. There has been no attempt in the literature to develop guidelines specifically for geoenvironmental applications.

Groundwater characteristics and flow conditions near a soil filter may affect filter performance. Specifically, erosion of fine soil particles within a base soil becomes more likely when brackish groundwater is replaced with fresh water. Fine soil particles may then disperse (become entrained in the flow with little applied groundwater velocity). These eroded particles migrate into filter soils, either becoming deposited within the pores, or flowing through the soil. The amount of deposition, or clogging, within a granular soil directly affects its ability to transmit flow. The design life of geoenvironmental systems can be limited by the effectiveness of the soil filter.

In some applications that make use of a granular layer, the traditional filter design may be too stringent to allow for the desired long-term drainage. For instance, in natural environments with small groundwater gradients, fine particles will likely not erode to the point which will cause instability of the base soil. In practice, a granular filter essentially creates a filter *within the base soil* through rearrangement of particles at the soil/filter interface. Particles too coarse to enter the filter will be stopped at the interface. These coarse particles then filter finer particles so that several small layers are created in the base soil. A more openly graded granular filter design should simply increase the thickness of the base soil affected by particle migration. Systems installed for long-term active containment of process-affected groundwater may benefit from an updated filter design that focuses on maintenance of permeability and thus long-term performance.

1.3 Objectives

The main research objective was to develop design criteria for granular drains to be used for long term operation in environmental applications. The secondary objectives were:

- to investigate the relationships between grain size distribution of drain materials and clogging by fines, and
- to investigate the effect of salinity on clogging.

These objectives were achieved through a literature review and a laboratory test program. The test program focused on hydraulic conductivity changes within granular soils when exposed to fines infiltration under brine and fresh water conditions and the following materials were used:

- three granular soils: French Drain sand, uniform sand, coarse graded sand, and
- three fine soils: kaolinite clay, Battleford Till fines, Regina Clay fines.

1.4 Hypothesis

Current design practice has led to the use of fine sand granular drainage layers that are based on stringent filtration criteria. The hypothesis of the current study is that coarser granular drains minimize the impact of clogging and provide a better alternative to traditional drain designs for long term environmental applications. Fines that enter a coarse granular drain should have less impact on long term overall permeability than fines that enter a fine granular drain. Furthermore, the low gradients present in groundwater collection applications should prevent extensive particle migration and therefore maintain base soil stability.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a literature review on the subject of granular drain design and drain clogging by fines. A general review of the development of drain design is presented in section 2.2. This is followed by a review of fine particle migration in base soils (section 2.3) and within sandstone cores (section 2.4). Section 2.5 discusses laboratory experiments that involved clogging sand columns with fines. Section 2.6 is a review of some of the methods that have been used to model permeability reduction in sands. Finally, section 2.7 presents a case study of a granular drain recently installed at a Canadian mine facility to help prevent migration of process affected water. Section 2.8 summarizes the literature review.

Soil filters are used in geotechnical engineering to protect adjacent (base) soils from eroding while permitting seepage. Indraratna et al. (2004) stated that, "the filter material should be such that it prevents penetration of base soil particles and yet it should be permeable enough to transmit water and avoid pore pressure build-up". Earth dams, retaining walls, and tunnels are commonly designed with soil filters. There are other applications in which granular soils may be expected to transmit large volumes of water, thus acting as a drain. These granular drains have typically been designed with filtration criteria, as instructed in the literature (NRCS, 1994). The terms drain and filter are sometimes used synonymously, though one term may be more appropriate depending on the application.

In some geoenvironmental applications, fluid being transmitted may have characteristics that are quite different than those of clean water.

> Soil filters assume paramount importance in the design of leachate collection systems in waste management and in the design of treatment barrier systems in site remediation. The performance of filters governs the life periods of these systems (Reddi, 1997).

Studies have found that soil filters can become clogged with fine particles (Baghdikian et al., 1989; Hajra et al., 2002; Reddi et al., 2000; Reddi et al., 2005). It has been shown that physicochemical processes involved in geoenvironmental applications influence particle release from base soils and entrapment in filters and thus become important in the design (Reddi and Bonala, 1997a). This study is limited to physical clogging of filters. Biological clogging is beyond the scope of the study.

2.2 Filter Design

A brief history of the development of filtration criteria is presented to demonstrate the conservative nature of the current state of practice. It has been established that "if the pore spaces in filters are small enough to hold the 85% size (D_{85}) of adjacent soils in place, the finer soil particles will also be held in place" (Reddi, 2003). This retention criteria concept was first suggested by Terzaghi in 1922 by the relationship:

$$D_{15} / d_{85} < 4 \tag{2.1}$$

where D_{15} represents the grain size at which 15% of the filter sand is finer and d_{85} is the grain size in the base soil corresponding to 85% finer. This relationship is presented graphically in Figure . Upper case "D" represents the grain size of the filter sand and lower case "d" represents a grain size of the base soil.

Terzaghi also theorized the relationship:

$$D_{15} / d_{15} > 4 \tag{2.2}$$

to ensure that the filter is sufficiently more permeable than the base soil. The filter sand design shown in Figure 2.1 satisfies these criteria. The filter sand values D_{10} and D_{60} will be explained shortly.

Laboratory studies that followed confirmed the retention criteria to hold true, though laboratory determined values of the ratio in equation (2.1) were as high as 6 (Bertram, 1940). Some studies determined other particle size relationships. The United States Army Corps of Engineers (USACE, 1953) determined that a coefficient of uniformity ($C_u = D_{60} / D_{10}$) of less than 20 is required to ensure nonsegregation during construction. Some relationships between D_{15} and d_{50}, and between D_{50} and d_{50} were also found (USACE, 1953, U. S. Bureau of Reclamation (USBR), 1960). These studies were performed mainly with cohesionless soils.

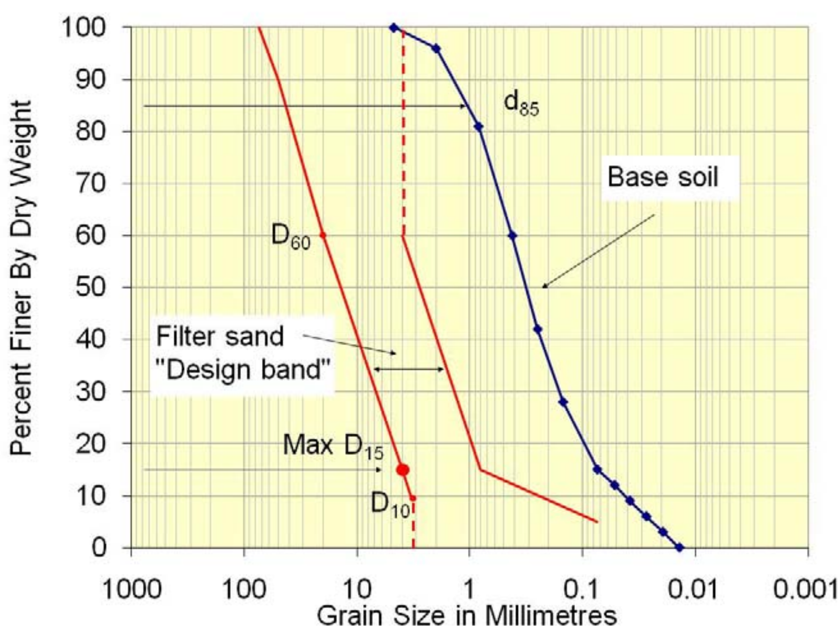

Figure 2.1 – Example filter sand design.

Extensive laboratory work was done by Sherard et al. (1984a, b) in the early 1980's. The results on cohesionless soils validated Terzaghi's theory while disproving the developed relationships between other particle sizes. The upper limit of the coefficient of uniformity was shown to be 6, rather than the previously determined value of 20. Sherard recommended that the filter should be designed based on the "regraded" base soil when the base soil contains gravel. To regrade a base soil, the percentage of material coarser than the 4.75 mm sieve is distributed evenly among the remainder of the sieve sizes. The test results on silt and clay base soils (Sherard et al., 1984b) are of particular interest. Sherard noted that there is no agreed upon quantitative filter design criteria for fine clays. Two laboratory tests were developed for the study. The first is the "slot" test, shown in Figure 2.2. The general test procedure involved delivery of a high pressure flow of water through a 13 mm slot cut through the centre of the base soil sample and into the filter material. The flow rates in the tests simulated a very high gradient that may occur in a concentrated leak through the core of a dam. The water pressure was gradually increased to a maximum of 590 kPa (hydraulic gradient of 1,000 to 2,000). At the start of each test, water pressures below 100 kPa were applied. No particles eroded at this pressure and thus the filters did not fail. Water pressure was then increased in increments of 50 kPa, until a concentrated leak of coloured water developed. This usually happened at water pressures above 150 kPa.

> For tests with successful filters, the flow rate rapidly decreased and the water became progressively clearer, finally sealing completely or stabilizing at a very small constant flow of clear water. … For unsuccessful filters, the surge of dirty water continued with no reduction in rate, and the test was commonly stopped after a few minutes. (Sherard et al., 1984b).

A second laboratory test developed during Sherard's study was the "slurry" test. In this test, there was no pre-formed hole placed through the soil sample, rather the sample was placed in the cylinder in slurry form, adjacent the filter material. Water was placed in the cylinder above the base soil slurry before a high pressure was applied from above. Again, pressure was applied until a concentrated leak developed. The slot test and the slurry test gave identical results in terms of the test variable of interest (the D_{15} filter boundary).

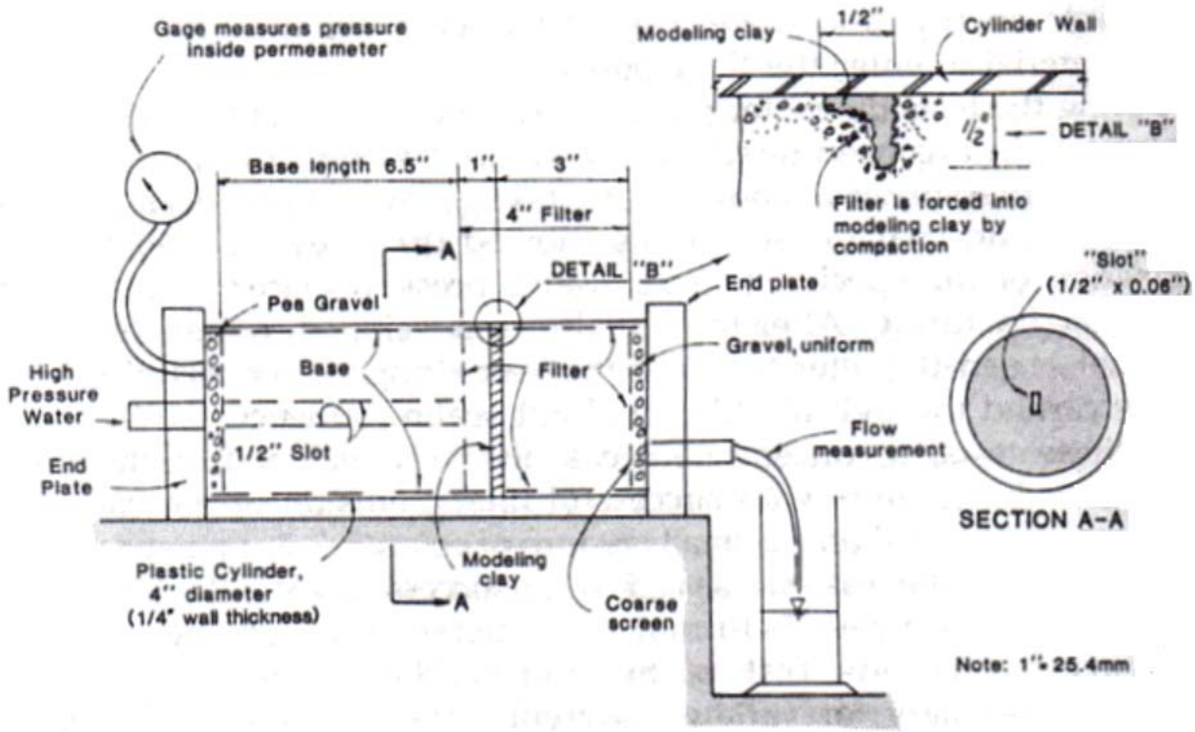

Figure 2.2 – Slot test apparatus details (Sherard et al., 1984b).

Thirty-six base soils were tested ranging from well graded sandy silts to very fine clays. Each base soil was tested with several filter materials. A unique D_{15} filter boundary (D_{15B}) was found to exist for each base soil. The results were accurate to 0.1 mm and repeatable. The D_{15B} determined for nearly every fine soil tested was greater than 1.0 mm. The relationship, D_{15B} / d_{85}, ranged from 9 to 57 and was not influenced by the proportion of clay sized particles. For many clays, the ratio was about 25.

> For typical clays without significant content of sand-size particles with d_{85} in the approximate range from 0.03 to 0.08 mm, the filter boundary, D_{15B} ranged from about 1.1

> to 3.0 mm. In this group…, there was no significant difference between the behavior of highly dispersive sodium clays and ordinary, nondispersive clays (Sherard et al., 1984b).

These D_{15} values are significantly higher than those recommended by current filter design standards for fine silt and clay base soils. Tests on soils with d_{85} values between 0.35 and 0.58 mm (sandy silts and clays) produced D_{15B} values from 5 to 10 mm. "For silts and clays with significant sand content (d_{85} of 0.1-0.5 mm), the existing main filter criterion, $D_{15}/d_{85} < 5$ is conservative and reasonable" (Sherard et al., 1984b).

A subsequent paper by Sherard and Dunnigan (1989) discussed the results of another test developed later in the same test program described above. The no erosion filter (NEF) test was similar in setup (Figure 2.3) to the slot test and the slurry test. Pressurized flow was directed through a preformed hole in the compacted base soil sample. Water pressure of 410 kPa was applied. The quantity of water coming through the filter was measured and observed over the five to ten minute tests. The goal of each test was to determine the filter boundary size, D_{15B}, at which "no visible erosion" took place within the preformed hole in the base soil. The NEF test was deemed to be better than the slot test and the slurry test for evaluating a critical filter (a filter to be used in a dam). Sherard and Dunnigan (1989) note that "the conditions in the NEF test simulate the most severe conditions conceivable that could develop in a dam from a concentrated leak through the core." The D_{15B} results for sandy silts and clays ranged from 0.7 to 1.5 mm, with no apparent correlation with the base soil particle size distribution. Some filters that were successful when tested with the slot or slurry tests failed the NEF test. In the slot or slurry tests, soils with relatively large d_{85} values (0.5 mm) returned filter designs with boundary sizes (D_{15B}) that proved inadequate to prevent erosion in the NEF test. The test results established the recommendation of filter design based on the proportion of fines (< 0.075 mm) in the base soil. The criteria for maximum D_{15} size within a filter are summarized as follows:

1) For soil group 1 (>85% fines), $D_{15} \leq 9 \times d_{85}$, but not smaller than 0.2 mm.

2) For soil group 2 (between 40% and 85% fines), $D_{15} = 0.7$ mm.

3) For soil group 3 (between 0% and 15% fines), $D_{15} \leq 4 \times d_{85}$.

4) For soil group 4 (between 15% and 40% fines), $D_{15} \leq (40 - A/40 - 15)(4 \times d_{85} - 0.7 \text{ mm}) + 0.7$ mm.

For soil group 3, the d_{85} can be based on the soil with no regrading. The A in the equation for soil group 4 is the percentage of fines in the base soil after regrading.

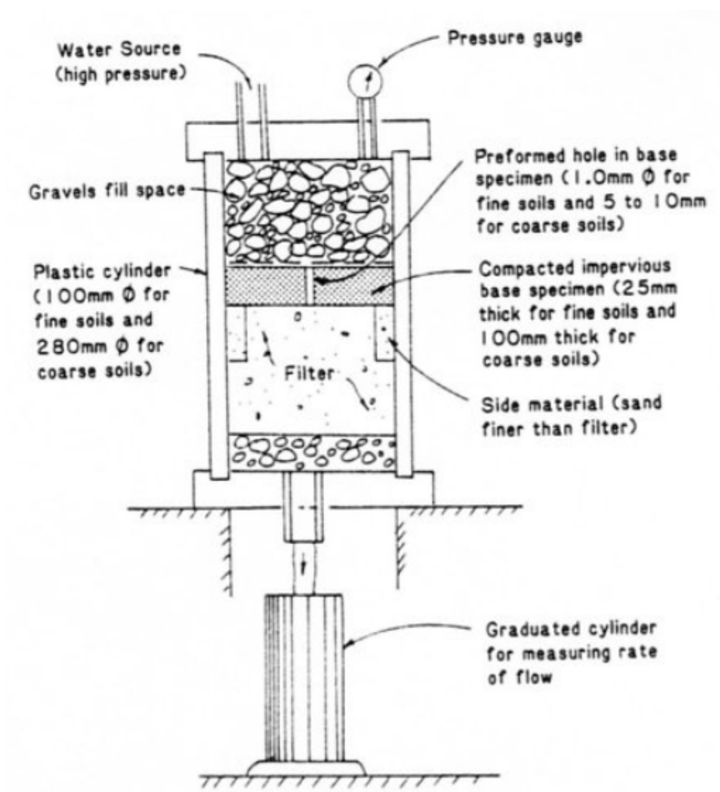

Figure 2.3 – No Erosion Filter Test Details (Sherard and Dunnigan, 1989).

The extensive test programs by Sherard et al. (1984a), Sherard et al. (1984b), and Sherard and Dunnigan (1989) were funded by the Soil Conservation Service (now National Resources Conservation Service) of the U. S. Department of Agriculture (USDA). The USDA has adopted the stringent criteria described above for the design of sand and gravel filters. It has been included in the National Engineering Handbook (NRCS, 1994) and is recommended for use wherever a granular filter is desired. A form of the criteria has also been adapted by the U. S. Bureau of Reclamation (Reddi, 2003).

Further laboratory research by Foster and Fell (2001) set out to determine the likelihood of continuous piping erosion (and ultimately failure) of dams constructed with filters coarser than the conservative design gradations established by Sherard and Dunnigan (1989). They conducted an analysis of past laboratory test data and conducted more filter tests to aid in the analysis. The results ultimately determined that there are other D_{15} boundaries of interest. An "excessive-erosion boundary" determined the D_{15} size of the filter for which a base soil would undergo "some erosion" before sealing under a concentrated leak. Base soils were again split into categories based on particle sizes. The extent of erosion appeared to depend on the size of the coarsest particles in the base soil. The excessive erosion boundaries for fine base soils were found to be 9 times the d_{90} or d_{95} size of the base soil. The worst-case "continuing-erosion boundary" is self explanatory in definition. For fine soils, the continuing-erosion boundary is equivalent or nearly equivalent to the excessive-erosion boundary (D_{15} = 9 x d_{95}). This means that a filter soil designed with a D_{15} size less than 9 times the d_{95} of the base soil will provide stability to the base soil. These values relate directly to the "filter opening size", originally presented by Sherard et al. (1984a), which is approximated by D_{15} / 9. Findings from previous studies have found that almost all particles that pass through a filter are smaller than D_{15} / 9 (Sherard et al., 1984a), and the maximum size of a particle that can pass through a filter (the allowable opening size) is equal to D_{15} / 5 (Kenney and Lau, 1985). Several base soils tested in Sherard's study were dispersive. The boundaries applied equally to dispersive soils.

Kenney and Lau (1985) did not agree that the d_{85} of the base soil should be used to design filters for broadly graded soils with a coefficient of uniformity, C_u, greater than six due to the subjectivity of "regrading" the material larger than the d_{85} size. The gradation curves of broadly graded soils extend over at least three logarithmic cycles. Glacial tills containing high quantities of sand and silt are commonly broadly graded. Kenney and Lau (1985) concluded that the amount of base soil loss was proportional to the percentage of particles that are smaller than the allowable opening size of the filter (D_{15} / 5).

Lafleur et al. (1989) presents an explanation of self-filtration, incorporating a homogeneous, non-cohesive, and broadly graded base soil and the drain material. Lafleur explains the concept graphically with a downward flow of water through a broadly graded soil in Figure 2.4. Water will carry into the filter particles finer than the actual opening size of the filter that exists at the soil-filter interface. Coarse particles are stopped by the filter and gradually brought in contact with each other. A succession of layers is created in which retained particles filtrate finer particles, which in turn, filtrate smaller ones until no particles can migrate. At this point equilibrium has been reached. A settlement, ΔH, of the soil results from the washout.

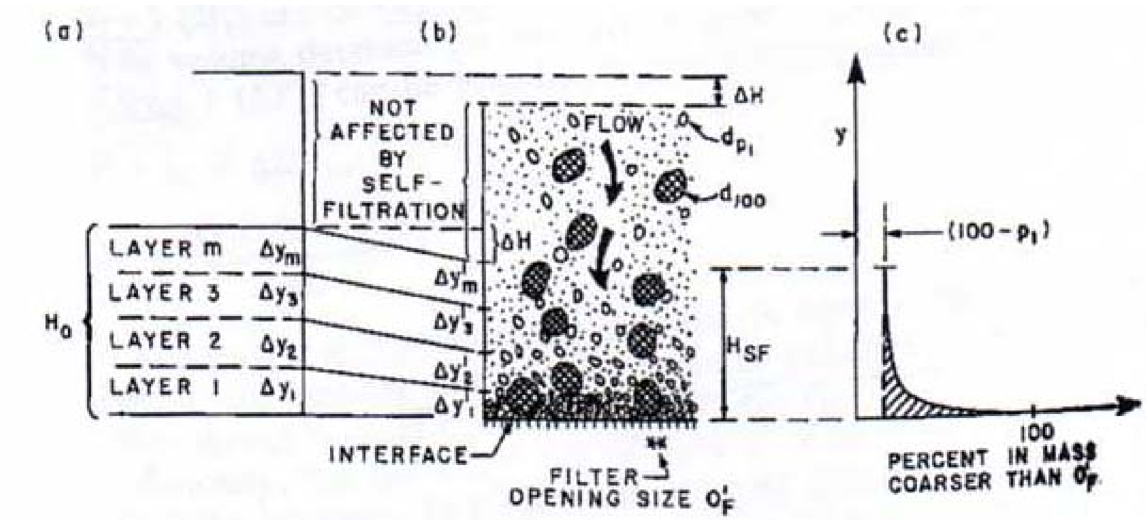

Figure 2.4 - Self-filtration induced by downward flow; Schematic conditions: (a) Before flow; (b) At equilibrium; (c) Distribution of particles coarser than filter opening size (Lafleur et al., 1989).

Three assumptions must be made:

1) The pore size of the remaining particles in each soil layer is equal to their minimum grain size divided by the actual retention ratio R'_R.
2) All the particles finer than the pores left by the retained particles are washed out from a layer of soil.
3) The dry density of the remaining soil in each layer is equal to the dry density of the original soil (Lafleur et al., 1989).

The relationship between D_{15} and d_{85}, originally described by Terzaghi (Equation 2.1) is sometimes referred to as the retention ratio, R_R. The allowable retention ratio, R_R, is commonly defined as being greater than D_{15} / d_{85} and is accepted as being equal to 4. The actual retention ratio, R'_R, is R_R times a factor of safety,

$$F_S = O_F / O'_F \tag{2.3}$$

where O_F is the allowable opening size of the filter; and O'_F is the actual opening size of the filter. These values have been shown to be D_{15} / 5 and D_{15} / 9, respectively (making F_s roughly 2).

The total height of soil where migration of particles took place, H_o, is:

$$H_o = m \times d_{100} \tag{2.4}$$

where d_{100} is the largest particle size that exists in the base soil and m is the number of layers from which particles migrated, given by:

$$m = \log C_B / \log R'_R \tag{2.5}$$

where C_B is the coefficient of broadness, which can be used to define the range of particles susceptible to being carried into the filter, which is given by the following equation:

$$C_B = O'_F / d_0 \tag{2.6}$$

Where d_0 is the smallest particle size that exists in the base soil.

Through a laboratory test program, Lafleur et al. (1989) confirmed that using the d_{85} value in the retention ratio produced filters that allowed large amounts of fine material to be washed out. Hydraulic gradients used in the tests ranged from 2.5 to 6.5. Lafleur proposed that the size of particles in the base soil that involve minimal particle migration in the filtering process should be used to determine filter boundary sizes. Since coarse particles do not get mobilized, they should not be considered in filter design. The "indicative base size" was found to be between d_{50} and d_{80} in linearly graded soils, and within the lower fraction of the gap for gap-graded soils. Linearly graded soils are either uniform or well graded soils that contain a good representation of all particle sizes present in the soil. The mass of particles washed out in Lafleur's lab tests was considerably lower than values predicted using his model. This was partly due to what Lafleur et al. (1989) termed "a slight interlocking between the finer silty and clayey particles of the bases." This further shows the difficulty in designing filters for fine soils in that the extent of particle migration can be too complex to quantify.

The literature has not provided design guidelines for granular drainage layers. Sherard et al. (1984b) discusses "noncritical" filters, such as those located upstream of an impervious dam core. Fine filters are not needed in noncritical locations, because "the quantity and energy of seepage water discharging from the base soil into the filter are too small to overcome the low cohesive forces in the soil." In these cases gradients are typically less than one. Sherard recommends that relatively coarse gravels can be used in these situations. Indraratna et al. (2004) refer to a "traditional gravel envelope" for toe drains, i.e. a well-graded gravel with 20-40% sand, with hydraulic conductivity of 150 to 300 m/day (0.17 to 0.35 cm/s).

Filter design within the groundwater well industry should also be described, as it resembles drainage in groundwater type applications. A properly designed well will result in high-yield pumping of groundwater over a long design life. A well always incorporates the use of a slotted riser pipe. A filter pack may be used adjacent the slotted pipe if the conditions in the aquifer deem it to be necessary. One such instance is an extensively laminated formation, consisting of alternating fine layers of fine, medium, and coarse sediment. The grading of the filter pack is based on the grain size of the finest layer to be screened. The filter pack ratio is the size differential between the formation materials and filter pack materials. Aller et al (1989) states that the D_{50} size of the filter material should range from 2 to 5 times the d_{50} size of the formation material. Driscoll (1986) presents a coarser and wider range of filter material, with the D_{70} size of the filter suggested as being 4 to 10 times the d_{70} size of the formation material. The lower ends of these ratios should be used if the formation materials are fine and uniform, whereas the coarser ends should be used for non-uniform formation materials. A fine formation material is considered to be one in which the 40% retained size is 0.25 mm or less. A smooth curve is then drawn through the chosen design point, with a coefficient of uniformity, (C_u, equal to D_{60}/D_{10}) less than 2.5. Uniform filter packs are preferable to graded ones, as they are more easily installed without segregation, and formation fines are more easily pulled into the well casing during well development. As an example, these design ratios are shown graphically in Figure 2.5 with the same base soil that was shown in Figure 2.1. The curves drawn through the fine and coarse ratios have a C_u of 2.2. In Figure 2.6, this filter design is compared with the design presented earlier based on laboratory studies for dam core filters. The filter sand design appears to be more uniform and for the most part, finer.

The intention of the filter pack in well design is to provide mechanical retention of the formation material so that sand-pumping wells can be avoided. Upon completing a groundwater well installation, the well is developed to remove fine material from the formation and the borehole (where drilling fluid or filter cake may exist), and creates a graded zone of sediment around the screen in a naturally developed well, thereby stabilizing the formation so that the well will yield sand-free water. For naturally developed wells, it is common practice to select a slot width that retains about 40 percent of the sediment in the formation adjacent to the screen. For filter-packed wells, the slot opening is selected to retain about 90 percent of the filter pack material.

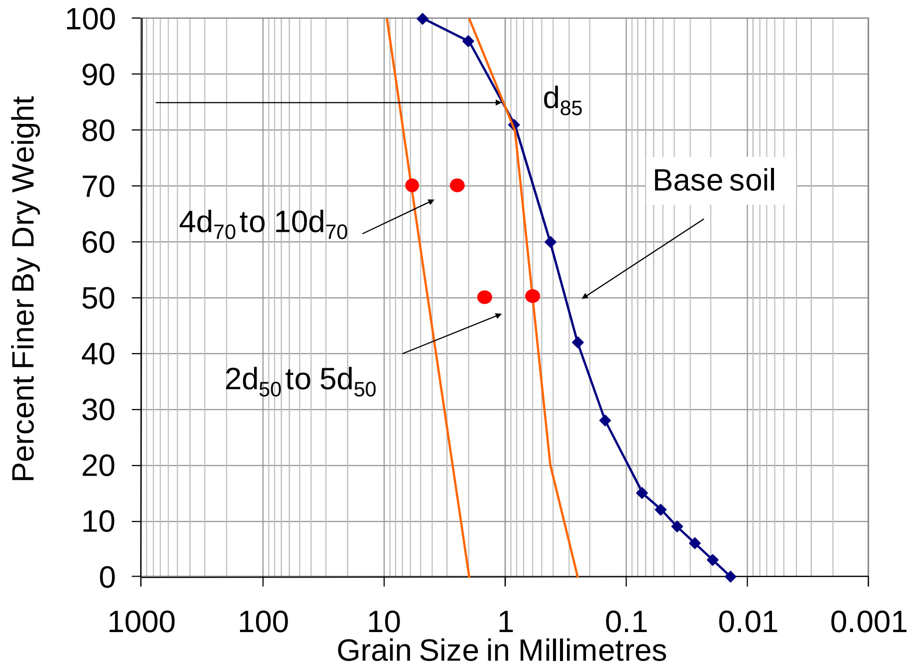

Figure 2.5 – Groundwater well filter pack design.

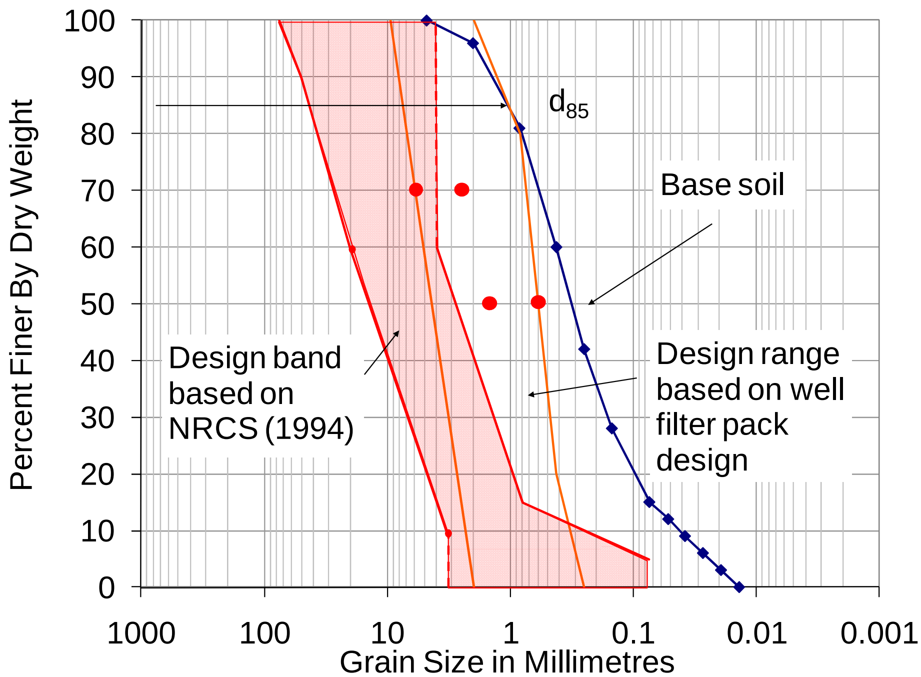

Figure 2.6 – Filter pack design compared with dam core derived filter design.

A drainage sand should promote removal of fine particles in a similar way that groundwater well development does. However, drainage layers differ from groundwater wells in that drainage layers may either have no slotted pipe, or a sufficiently long drainage path between the base soil (formation soil) and the pipe. Further to this, drainage layers are not developed to remove fine soil particles from near the interface. Natural particle migration is the only means of fine soil particles entering a drainage sand.

This section presented a review of past studies that dealt with the design of granular filters. Current practice involves measuring the particle size distribution of the base soil and manufacturing a granular filter soil or "design band" that a soil must fall within to protect the base soil from excessive erosion. There are two questions pertinent to the current research: 1) do filtration criteria apply in these low-gradient applications? and 2) how should a granular soil be designed to promote long-term drainage while providing stability to the base soil under low-gradient groundwater-type flow?

The discussion concerning noncritical filters (above) may imply that filtration criteria should not apply in groundwater collection applications. However, since particle mobility can be affected by a decrease in salt concentration in the groundwater, it is proposed that filtration criteria does apply. Current design practice taken from the NEF test by Sherard and Dunnigan (1989) requires maximum filter D_{15} values (D_{15B}) of 0.2 to 0.7, depending on the proportion of fines in the base soil. Laboratory results by Sherard et al. (1984b) indicate that dispersive clays were protected from significant erosion by filters with D_{15B} sizes between 1.2 and 2.7. If these dispersive soils subjected to high gradients can be successfully protected by relatively coarse filters, it follows that a granular soil intended for groundwater collection applications can be made to be coarser than the current accepted practice.

2.3 Particle Migration

It has been shown that filter criteria have been developed based on "straining" mechanisms. This implies that particles will migrate within the base soil and filter/drain soil. This section will present a review of the literature dealing with the ways in which particles can become entrained in flow.

Erosion of soil particles may occur under two separate conditions in the subsurface; one condition is chemical and the other is physical. The chemical effects include dissolution of the cementing agents between clay and sand, and dispersion by increasing repulsive forces (Reddi and Bonala, 1997a). The physical effects causing surface erosion involve hydrodynamic forces in the soil pores, which creates shear stresses on the soil. When the shear stresses are high enough, removal of aggregates or flocs of particles will occur due to the breakup of interparticle bonds (Arulanandan and Perry, 1983).

A fundamental parameter to classify erodibility characteristics is the critical shear stress, τ_c. The critical shear stress is defined as "the value of the stress for zero sediment discharge" (Arulanandan and Perry, 1983). The critical shear stress of a soil is influenced by factors such as the clay type and amount, pore and eroding fluid compositions, pH, and temperature. Reddi (1997) observed that experimental evidence "indicates that beyond a critical velocity (which corresponds to critical shear stress), the erosion rate bears a linear relationship with hydraulic gradients." This is illustrated by the following rate relationships:

$$\delta C/\delta t = \beta\,(V - V_c); \quad V > V_c \tag{2.7 a}$$

$$\delta C/\delta t = 0; \quad V < V_c \tag{2.7 b}$$

where C = particle concentration in the pore stream (M/L^3); t = time; V = Darcy velocity (L/T); V_c = critical velocity (L/T); and β = change in erosion rate per unit increase in Darcy velocity (M/L^4). Reddi and Bonala (1997a) summarize the experimental methods for measuring (directly or indirectly) the critical shear stress: 1) the "dispersion test", which compares the percent fines dispersed in a sample with and without a chemical dispersant, 2) the "pinhole test", which measures particle removal within a 1 mm hole in a soil sample, and 3) the "rotating cylinder test", which measures the stress required on the surface of a soil sample to disperse clay particles.

The subsurface conditions near active containment drains at potash mines are of particular interest when discussing soil erodibility. Since sodium chloride (NaCl) concentrations in the pore fluid can reach concentrations several times that of sea water, there is an effect on the diffuse double layer of clay particles. Clay dispersion can occur when double-layer repulsion overwhelms van der Waals attraction and interparticle repulsive forces can then become high. Dispersive clays exist where relatively clean (low salinity) pore fluid is introduced to clay particles that have a high percentage of exchangeable sodium, causing desorption of the ions (Khilar et al., 1985; Yong et al., 1979). Khilar and Fogler (1984) determined that the double-layer force of repulsion may be the dominant cause of particle release. Erosion of base soils can occur more readily (i.e. at lower velocities) when brine is replaced with fresh water.

Arulanandan et al. (1975) developed the rotating cylinder test to measure the critical shear stress of a soil. Table 2.1 shows the effect of NaCl concentration in the eroding fluid. An increase in electrolyte concentration leads to a reduced erodibility of soils.

Table 2.1 – Erosion rates for a soil with different concentrations of pore fluid (rewritten from Arulanandan et. al, 1975).

NaCl concentration in the eroding fluid	Soil pore fluid SAR	Erosion rate/shear stress, in g/min per dyne	Erosion rate normalized with that of distilled water
Distilled water	36.8	0.0114	1
0.001 N	35.2	0.0057	0.5
0.006 N	31.3	0.0012	0.11
0.02 N	36.8	0	0
0.1 N	36.8	0	0

2.4 Clogging Experiments on Sandstone Cores (No Particles in the Influent)

Some studies performed with hydraulic flow through sandstone cores are of interest due to the problem of water sensitive sandstones. This issue is of practical importance in the oil and gas industry due to the common practice of pumping oil from sandstone horizons. The phenomenon is described by Khilar and Fogler (1984) as follows: when flow is switched from salt water to fresh water through a sandstone core, clay particles are released from pore walls. The particles migrate with the flow and become trapped at pore throats, decreasing the permeability.

Khilar and Fogler (1984) showed that a critical salt concentration (CSC) exists, below which particles are released from pore walls. Laboratory testing showed that a stepwise decrease in NaCl concentration through a Berea sandstone showed no reduction in permeability until the influent concentration dropped below 4250 ppm (0.07 M) NaCl. No clay particles were detected in the effluent before this concentration was reached. The sample contained about 8% clay by mass, primarily kaolinite with some illite. No swelling clays (montmorillonite) were present. It was found that the CSC was strongly dependent on the nature of cations present. When divalent cations were present, the CSC decreased, indicating the unlikeliness of particle release given a calcium chloride solution in the sample.

In sandstone, there also exists a critical rate of salinity decrease for particle capture (Khilar et al., 1983). Considering flow through a sandstone core, a given drop in salt concentration below the CSC will release a number of clay particles. An abrupt decrease in salt concentration will release a large number of clay particles in a short time. The degree of clogging depends on the number of clay particles present in suspension in the pores. Clogging can occur due to "log-jams" at pore throats; however, if the salt concentration is decreased slowly, clay particles are released over a longer period of time. Particle concentrations are lower and particles can move more easily through pore constrictions under these conditions.

A study similar to Khilar et al. (1983) was performed by Faure et al. (1996). This study described the transport of clay particles out of a column when a salinity gradient was applied. Experiments were conducted on a column filled with a mixture of sand and 5% bentonite. The initiation of movement of the bentonite particles was brought about through a linear decrease in sodium chloride concentration being fed through the column. If the sodium chloride concentration was then kept constant, the fine particle concentration leaving the column decreased to zero. Faure found that a value of NaCl of 0.16 M (9400 ppm) was the upper threshold, above which no particle migration out of the column was observed.

The studies conducted on sandstone cores are significant with respect to the current study. Flow conditions within the drain resemble those in sandstone core tests. In both cases, sand particles are in contact with each other while fines are located in the sand pores. The relative salinity of the water affects whether particles will become entrained in the flow and/or flocculate. Granular drains installed to intercept highly saline groundwater could experience minimal fine particle migration over the course of normal operation, as long as the groundwater salinity content remains above a relatively low threshold value, on the order of 0.08 M (Khilar et al., 1983) or 0.16 M (Faure et al., 1996). Sea water is approximately 0.5 M NaCl. Fines migration from the base soil into the drain could be triggered by a momentary drop in salinity. Re-established high salinity would then keep the fines in place in the drain soil, similar to the sandstone in the referenced studies.

2.5 Clogging experiments in sand packs (particles included in the influent)

Permeability changes in granular filters/drains are important when considering the long-term requirement to transmit water. Movement of fine soil particles into a filter can occur in any groundwater environment.

> In a natural environment, colloid-size particles exist often in significant quantities, and the transport of these particles, which is not necessarily associated with ground instability, has been well documented in the literature (Reddi and Bonala, 1997b).

Several laboratory test programs have been conducted to determine the effects of fine particle clogging on sands (Baghdikian et al.; 1989, Reddi et al.; 2000, Hajra et al.; 2002, Reddi et al., 2005).

Baghdikian et al. (1989) used samples of Ottawa sand injected with suspensions of kaolinite and bentonite under varying ionic strengths. The results of the study showed that rates of permeability reduction were higher with an increase in ionic strength in the permeant (Figure 2.7). Potassium chloride (KCl) solutions at ionic strengths up to 0.1 M were used as the permeant. Other results indicated that greater concentrations of particles increased the rate of permeability reduction, as expected. Further results showed that kaolinite did not reduce permeability significantly at low ionic strengths. Injection of bentonite showed a greater rate of permeability reduction than for kaolinite, most likely due to "the bridging capability of bentonite and, therefore, the formation of aggregates."

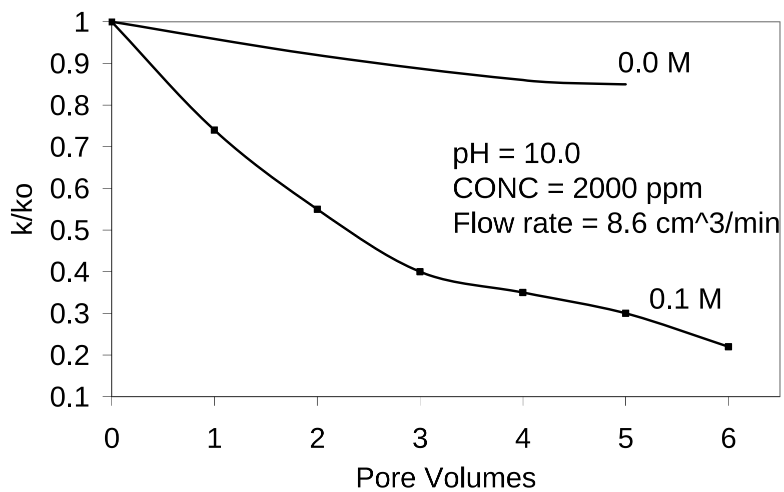

Figure 2.7 – Effect of KCl concentration with a kaolinite suspension (redrawn from Baghdikian et al., 1989).

Baghdikian et al. (1989) found that permeability reduction caused by injected particles into a porous medium can be caused by two mechanisms:

- particles larger than a pore throat become trapped, or
- particles much smaller than the pore sizes deposit uniformly in pores.

The second mechanism is dominant when an attractive surface potential energy exists between the sand and the fines. These include gravitational, inertial, hydrodynamic, electric double layer, and van der Waals forces.

A more recent study by Hajra et al. (2002) conducted similar tests on concrete sand injected with suspensions of kaolinite. Permeants consisted of potassium chloride and sodium hydroxide (NaOH) solutions. The results are similar to the previous study in that the rate of permeability reduction is higher with high ionic strengths in the permeating fluid (Figure 2.8).

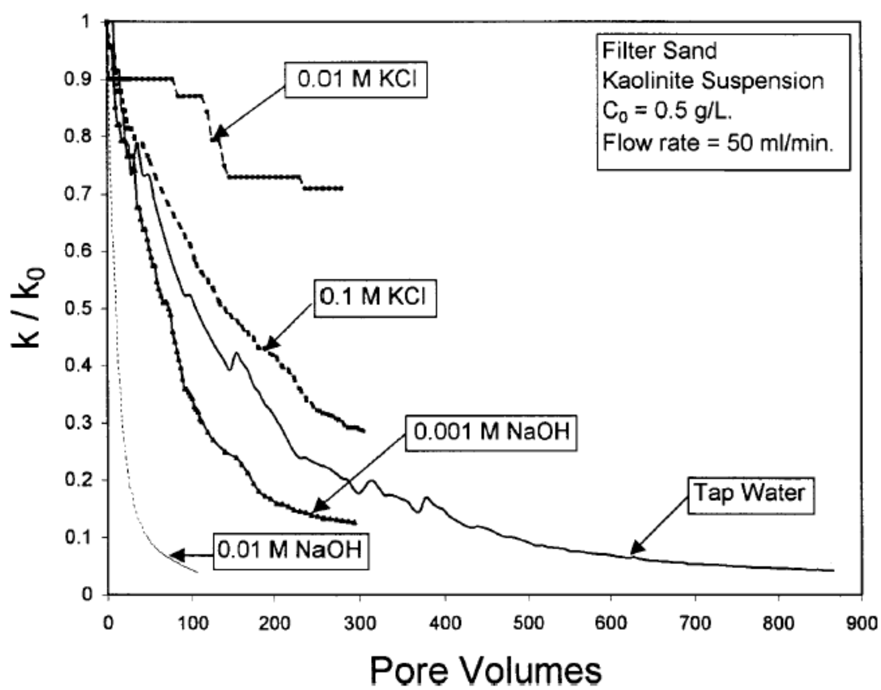

Figure 2.8 – Permeability reduction profiles under several ionic strength conditions (Hajra et al., 2002).

Baghdikian et al. (1989) notes that coagulated floccules likely exist at high ionic strengths. The floccule size could not be measured with the particle-size analyzer used in that study because the instrument was only able to measure very small concentrations of particles (1 to 10 ppm). Hajra et al. (2002) used equipment that enabled an accurate determination of the particle size distributions at varying ionic strengths (Figure 2.9). It was found that flocs were smaller in number but greater in size with increasing ionic strength. A greater reduction in permeability was found with the larger flocs infiltrating the concrete sand samples. The difference in flocculation behaviour between NaOH and KCl caused greater permeability reduction with NaOH as the permeating fluid.

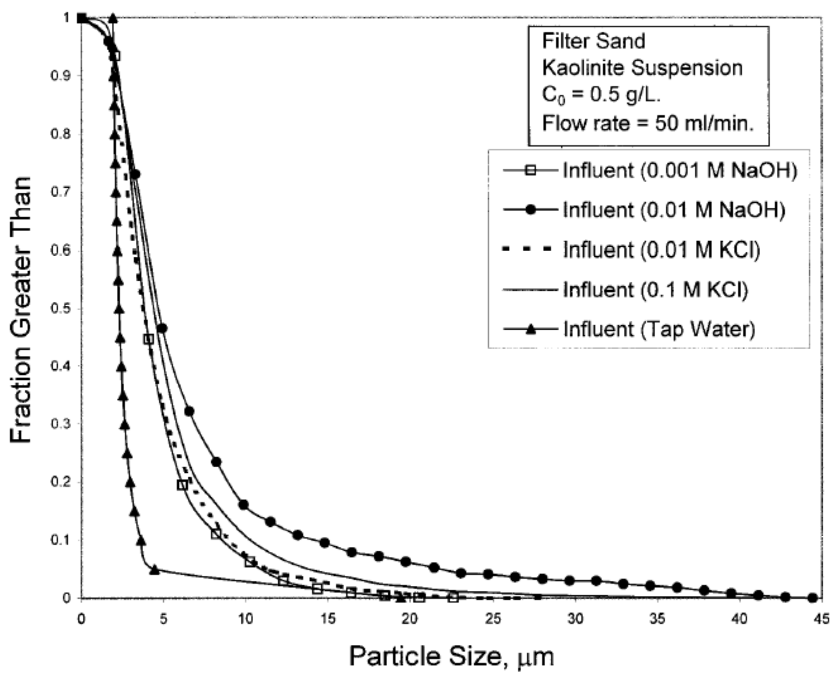

Figure 2.9 – Influent particle size distributions at different ionic strengths (Hajra et al., 2002).

A similar experimental test program is reported by Reddi et al. (2000) for tests on concrete sand with the influent consisting of tap water only. Polystyrene microspheres were used along with kaolinite clay as the injected particles. The results indicate that permeabilities were reduced by more than an order of magnitude after 300 to 600 pore volumes of flow through drain samples.

Polystyrene microspheres and kaolinite particles were used in concentrations of 0.5 to 1.0 g/L. Higher particle concentrations led to faster reductions in permeability; however, the difference in influent particle size did not affect permeability significantly. The majority of kaolinite particles used in the flow through tests were smaller than 4 μm. Some of the polystyrene spheres, however, were as large as 50 μm. It was found that approximately 5% of the kaolinite particles flocculated during the tests. This resulted in permeability reduction rates similar to concentrations of the inert microspheres, which did not flocculate (Figure 2.10).

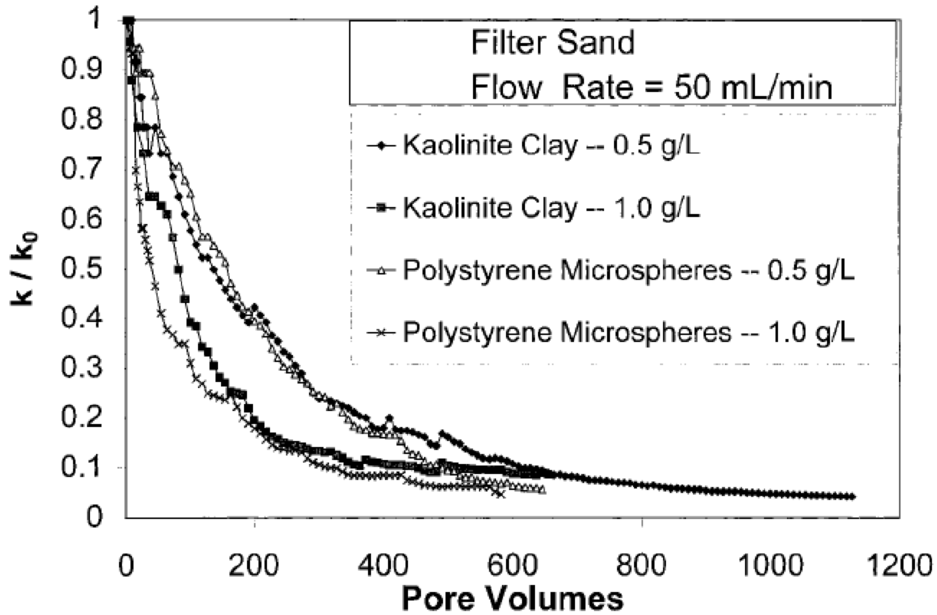

Figure 2.10 – Effects of particle concentrations and particle sizes on permeability reduction (Reddi et al., 2000).

A follow-up paper by Reddi et al. (2005) described the differences in clogging mechanisms between the conditions of constant flow rate and constant head using the same experimental setup and materials. The condition of constant head resulted in a greater permeability reduction than the condition of constant flow rate, given the same initial flow rate. This was due to the difference in flow characteristics in individual pores. Once particles settle in pores, they remain there under constant head conditions, whereas hydrodynamic forces may re-mobilize particles under constant flow rate conditions.

Under constant head conditions, pore velocities decrease with time due to particle clogging. There is a greater likelihood of particle deposition at lower flow rates. When comparing permeability reductions with time, the rates of reduction are not significantly different over most of the duration of the tests (Figure 2.11). This is mainly due to the fact that when considering the condition of constant head, the number of pore volumes exiting the sample gets smaller with time. Therefore, relating permeability reduction to pore volumes of flow results in a more pronounced difference between the two methods (Figure 2.12). From these figures, it is also apparent that the concentration of particles inserted into the sample has an influence on the rate of permeability reduction.

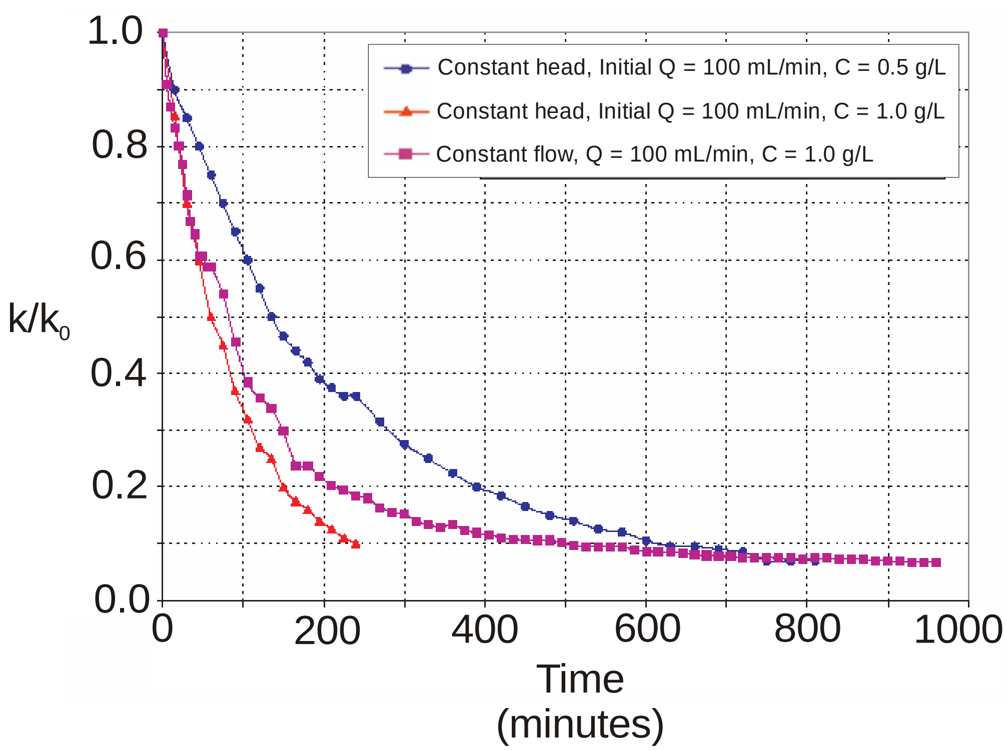

Figure 2.11 – Permeability reduction vs time (Reddi et al., 2005).

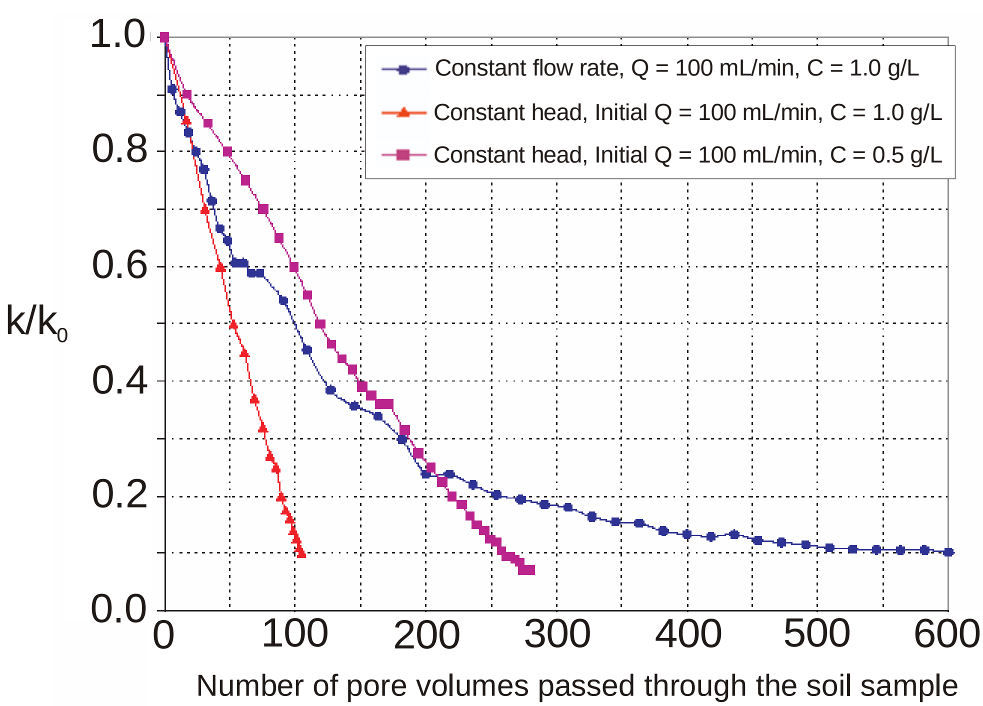

Figure 2.12 – Permeability reduction vs pore volumes (Reddi et al., 2005).

2.6 Modeling of Permeability Reductions in Sand Packs

The literature review shows the results of analytical and numerical modeling, which have helped to predict particle migration from a base soil into a granular filter, as well as particle deposition within a filter. Several studies have dealt with modeling particle capture in sand pores in an attempt to explain experimental results. These studies include those by Reddi et al. (2000 and 2005) and Hajra et al. (2002). The Kozeny hydraulic radius model was used in these cases. With this model, the granular soil is idealized as an ensemble of parallel capillary tubes of various diameters (Figure 2.13). Particle deposition rates in the pore tube are a function of flow rate, concentration of particles, and the probability of deposition.

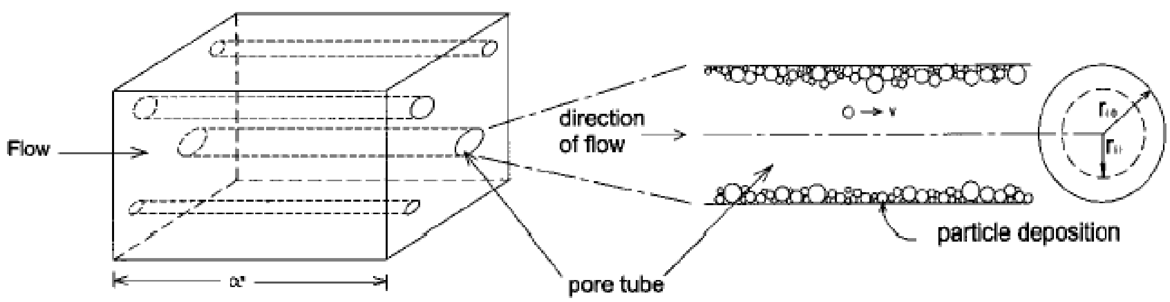

Figure 2.13 – Capillary tube representation (Reddi et al., 2000).

The model calculates permeabilities over time steps, based on a gradual reduction in pore size due to particle deposition. This model is an extension of the Hagen-Poiseuille equation, and is expressed as:

$$k = C_s n\left(\frac{\gamma}{\mu}\right)\left[\frac{1}{4\sum_i^1 \frac{f(d_i)}{d_i}}\right]^2 \tag{2.8}$$

where k = permeability [L/T]; C_s = shape factor (1/32) for cylindrical pores (unitless); n = porosity (unitless); γ = unit weight of water [F/L^3]; μ = absolute viscosity of water [FT/L^2]; d_i = ith pore diameter [L]; and $f(d_i)$ = volumetric frequency of the pore group d_i (unitless).

The flow rate in the model is expressed using the Poiseuille law:

$$q(r_i) = \frac{\pi \gamma J}{8\mu} r_i^{\ 4} \tag{2.9}$$

where J is hydraulic gradient across the pore tube and r_i is the tube radius [L]. Finally, the probability of deposition was also expressed with a closed form solution in these studies, which is found to be:

$$p(r_i, a_j) = 4\left[\left(\frac{\vartheta a_j}{r_i}\right)^2 - \left(\frac{\vartheta a_j}{r_i}\right)^3\right] + \left(\frac{\vartheta a_j}{r_i}\right)^4 \tag{2.10}$$

where a_j is the radius of the particle deposited in the pore tube and θ is a lumped parameter. This relationship "conceptualizes that the probability of particle capture is equivalent to a fraction of total flow in the annulus of a pore tube between r and (r – θa)" (Reddi and Bonala, 1997b). This is illustrated in Figure 2.14. Rege and Fogler (1988) listed the factors that affect the value of θ as "fluid velocity, ionic strength, pH, fluid properties, and particle density and concentration." In their paper, experimental results were matched with a network model to determine an exponential equation for θ:

$$\vartheta = \vartheta_o \exp\left[-v(r_i)/v_{cr}\right] \tag{2.11}$$

where θ_o is a constant dependent on ionic conditions; $v(r_i)$ is the velocity of flow in the pore tube; and v_{cr} is the critical velocity beyond which no particle clogging is likely. "The value of θ_o is primarily affected by changes in the ionic strength and pH" (Rege and Fogler, 1988).

Using equations (2.9) and (2.10):

> [T]he total number of particles of various radii deposited in each pore tube may be estimated as a function of time. The change in pore radius as a result of the particle deposition would depend on the deposition morphology, which can neither be predicted nor be modeled from a practical standpoint. The effect of particles is merely to increase the resistance to flow and thus effectively reduce the pore size. (Reddi et al., 2000).

For modeling purposes, it is essential to transform the drain particle size distribution to a pore size distribution. This can be done in the lab by relating suction pressures to the volume of water content released at each pressure. The capillarity principle is used to transform suction pressures to pore diameters. Reddi et al. (2000) refers to this as the Haines method. Baghidikian et al. (1989) used mercury injection porosimetry to find the pore size distribution of sand samples. Alternatively, or as a check on the laboratory procedures, the following expression relates pore radii (r_i) to particle radii (R_i):

$$r_i = (4eR_i^3/3\alpha^*)^{1/2} \tag{2.12}$$

where e is the void ratio and α^* is the parameter representing effective pore length [L]. This relationship was originally proposed by Arya and Paris (1981). Values for α^* were later found to vary from 3 to 15 mm for sands and silts (Reddi and Bonala, 1997b).

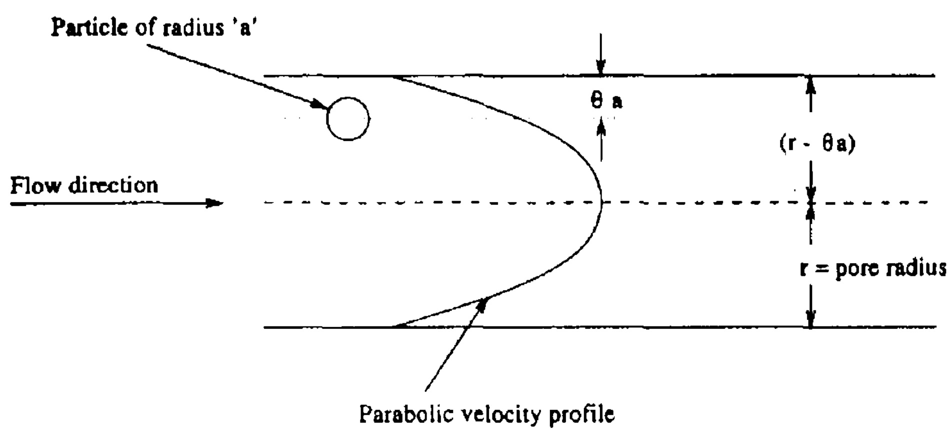

Figure 2.14 – Estimation of particle capture in a pore tube (Rege and Fogler, 1988).

Another modeling approach is based on mass conservation principles. The model predicts particle release from a base layer and entrapment in a filter layer (Figure 2.15). A major assumption is that particle concentrations in the pore stream are small enough to cause insignificant changes in porosity. The governing equation for particle transport is

$$\frac{\partial C}{\partial t} + V\,\frac{\partial C}{\partial x} + \frac{\partial S}{\partial t} = 0 \tag{2.13}$$

where C is the mass of fine particle concentrations per unit pore volume; S is the mass of fine particles deposited per unit original pore volume; and x, t is the space and time coordinates. The equation uses only advective transport.

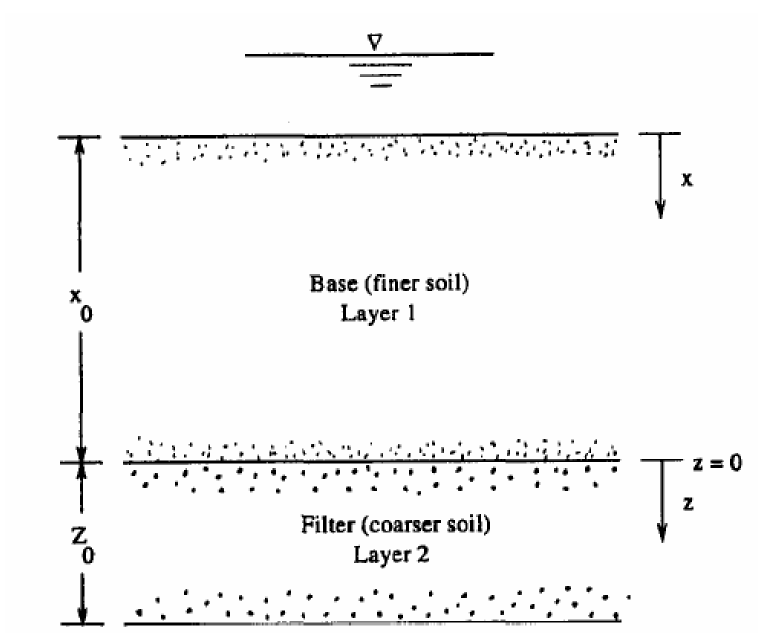

Figure 2.15 – Schematic of base soil adjacent filter soil (Reddi and Bonala, 1997b).

One equation can be developed for each layer, depending on the processes of particle generation in the base soil and particle deposition in the filter. The governing equation for particle transport in layer 1 is

$$\frac{\partial C}{\partial t} + V_1 \frac{\partial C}{\partial x} - \beta(V_1 - V_{c1}) = 0 \tag{2.14}$$

where V_1 is the pore velocity in layer 1; β is the rate of erosion; and V_{c1} is the critical velocity in layer 1. The governing equation for particle transport in layer 2 is

$$\frac{\partial C}{\partial t} + V_2 \frac{\partial C}{\partial z} + \lambda C = 0 \tag{2.15}$$

where λ is a deposition coefficient. "The host of physicochemical interactions involved between the migrating particle and the porous matrix are incorporated in the coefficient λ" (Reddi and Bonala, 1997b).

Closed form solutions were generated for S and λ. The mass of fine particles deposited, S, increases with an increase in erosion rate from the base soil and an increase in the deposition coefficient. The following variables are used to determine λ: the lumped parameter, θ, pore velocity, V, migrating particle size, a, and filter soil characteristics (m and b, the parameters of the lognormal distribution of the pore size density function). The effect of θ_o on the deposition coefficient is shown in Figure 2.16. Figure 2.17 shows that:

> [A] slight increase in time rate of deposition due to increased advection dominates the process at relatively low velocities, whereas at high velocities approaching critical velocity, particle deposition is prevented because of increased hydrodynamic forces (Reddi and Bonala, 1997b).

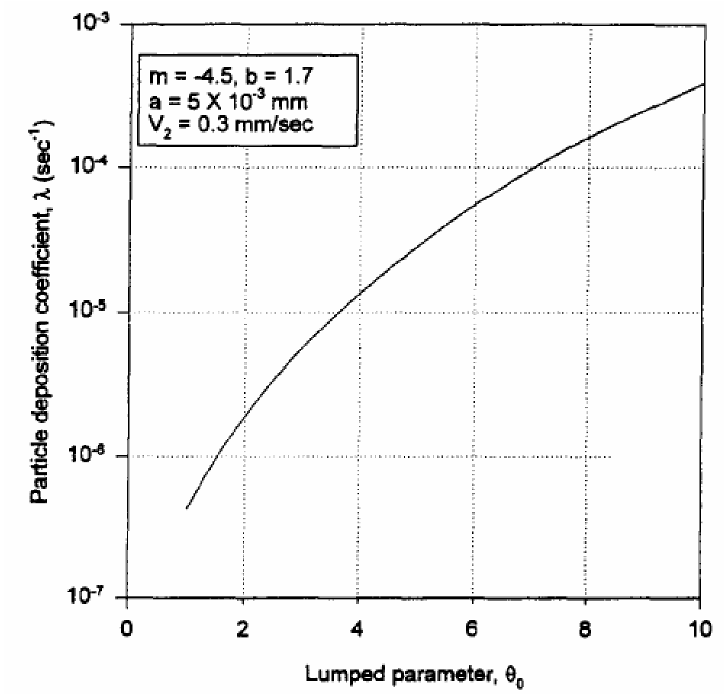

Figure 2.16 – Effect of lumped parameter (θ_o) on deposition coefficient λ (Reddi and Bonala, 1997b).

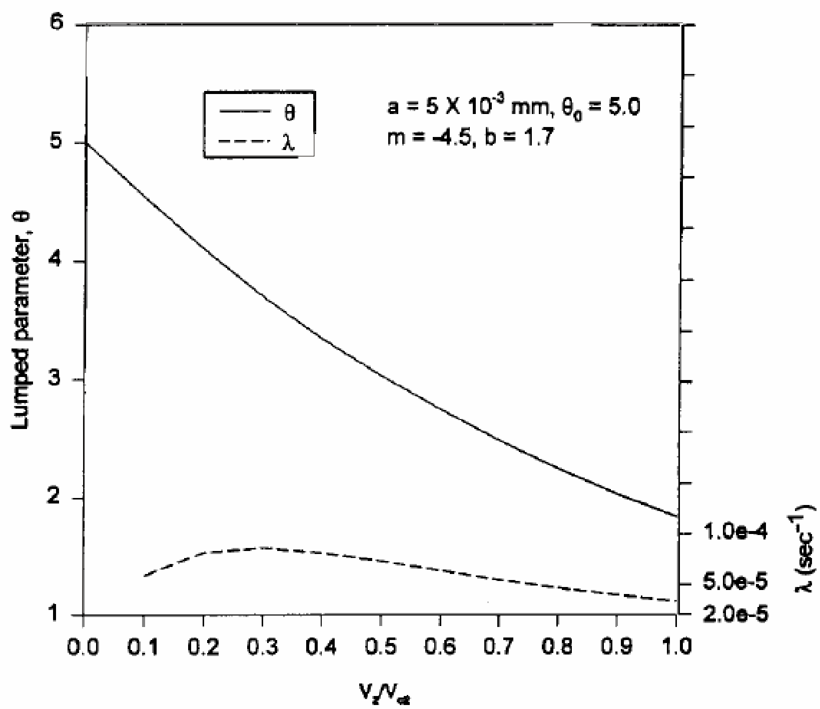

Figure 2.17 – Effect of pore water velocity on deposition coefficient λ (Reddi and Bonala, 1997b).

Reddi and Bonala (1997c) presented figures with experimental results from past investigations (Rege, 1988; and Arulanandan et al., 1975) that illustrate the effect of increasing salt concentration on filter clogging. Figure 2.18 shows that increasing salt concentration produces higher values of θ_o, and larger clay floc particle sizes, a. Figure 2.19 shows that increasing salt concentration has an opposite effect on deposition and erosion processes. A low salt concentration has the potential for a greater rate of erosion, most notably in soils with a high sodium adsorption ratio (SAR). These soils tend to have sodium cations, rather than other cations, adsorbed at exchange sites. The sodium adsorption ratio is a comparison of sodium ions to the combination of calcium and magnesium ions in the soil. More precisely, it is the amount of sodium divided by the square root of half the sum of the amounts of calcium and magnesium, where ion concentrations are given in milliequivalents per litre. Deposition in the filter is less likely at low salt concentrations than at high concentrations; however, "these opposing trends make it difficult to generalize the overall effect of change in pore fluid composition on filter clogging" (Reddi and Bonala, 1997c). Finally, Reddi (1997) cautions that λ "is not readily available for fine particles in natural subsurface systems" due to differences between natural subsurface conditions and controlled flow conditions in a granular bed filter. Flow rates are much lower in natural systems.

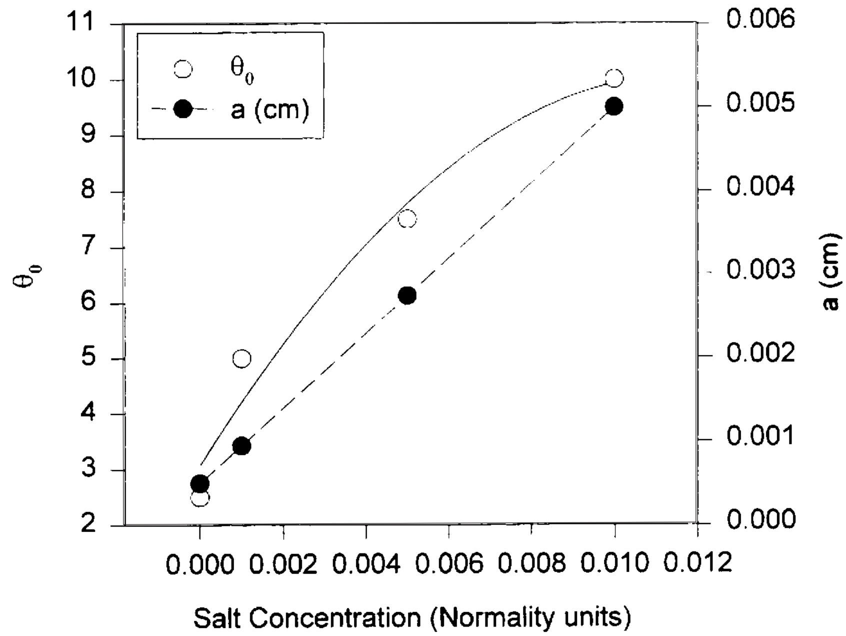

Figure 2.18 – Variation in θ_0 and a with salt concentration (Reddi and Bonala, 1997c).

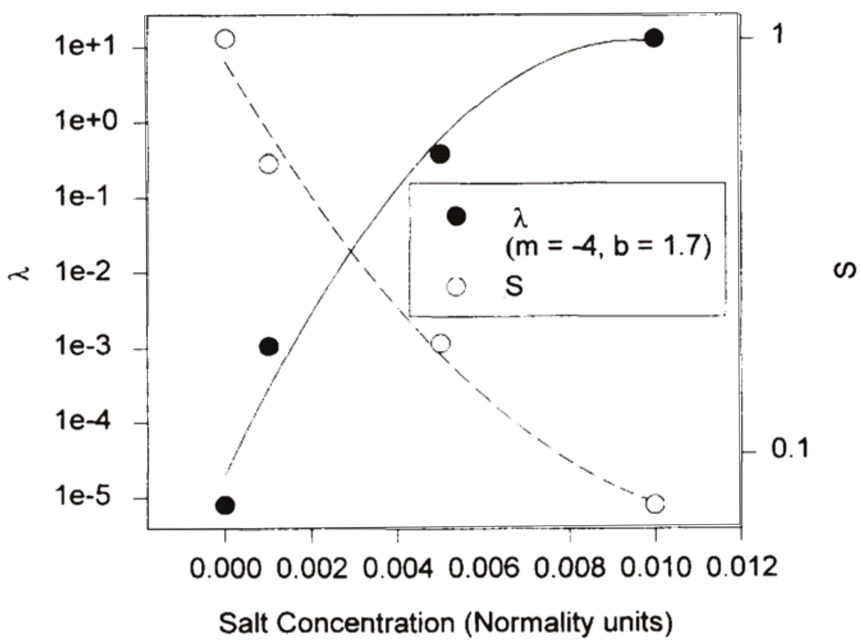

Figure 2.19 – Variation of S and λ with salt concentration (Reddi and Bonala, 1997c).

This section illustrated the difficulty in theorizing particle motion and capture in the subsurface, and that many variables are involved. The models estimate the probability of particle capture within a granular soil based on flow rate, pore water salinity, particle and pore diameter, and filter soil characteristics. The information most relevant to the current study is the affect that salt concentration in the groundwater (sodium chloride in particular) has on particle release and deposition. Low salinity is required for particles to be released (under normal groundwater flow conditions). Low levels of salinity do not promote deposition within a granular soil.

2.7 Review of a French Drain installation

In order to demonstrate the current state of practice concerning granular drain/filter design, a case study review of a French Drain installation is presented. This section describes the design of the granular drainage material, other design considerations, issues with installation, and drain performance. The French Drain sand used in the current laboratory study matches the designed material used in this installation.

A French Drain was chosen as a containment technique at a Canadian mine facility in order to control the rate of shallow groundwater migration from the tailings management area. The project to be described herein consisted of four phases:

- field investigation,
- design,
- construction, and
- monitoring

2.7.1 *Field Investigation*

A stratigraphic drilling program was initiated in order to map the lithologies along the proposed route. Boreholes were drilled along the alignment at approximately 100 m spacing. Disturbed samples were obtained from the auger flights and logged on site. Selected samples were obtained for laboratory testing to aid in the design of the granular backfill. Boreholes were terminated once unoxidized, unfractured glacial till was encountered. This depth was on the order of 10 m in most boreholes. The geology of a typical cross-section is shown in Figure 2.20. Sandy silt till of the Battleford formation was present along the route. Small sand lenses were present in some areas. In addition, the groundwater table was one to two metres below ground level. There existed a slight west to east gradient in the region. Figure 2.21 superimposes the location of the French Drain over the typical cross-section. Groundwater drawdown (and removal) occurs both upgradient and downgradient the drain. This is one advantage of a drain over a passive barrier such as a slurry wall.

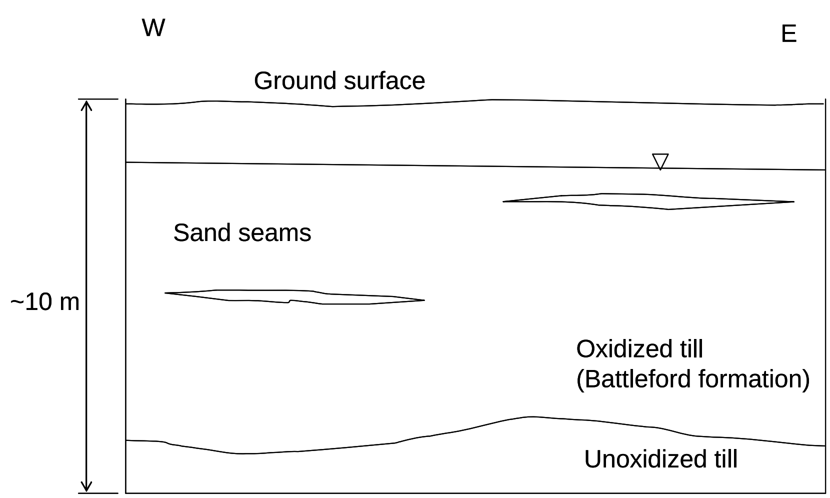

Figure 2.20 – Typical cross-section (pre-construction).

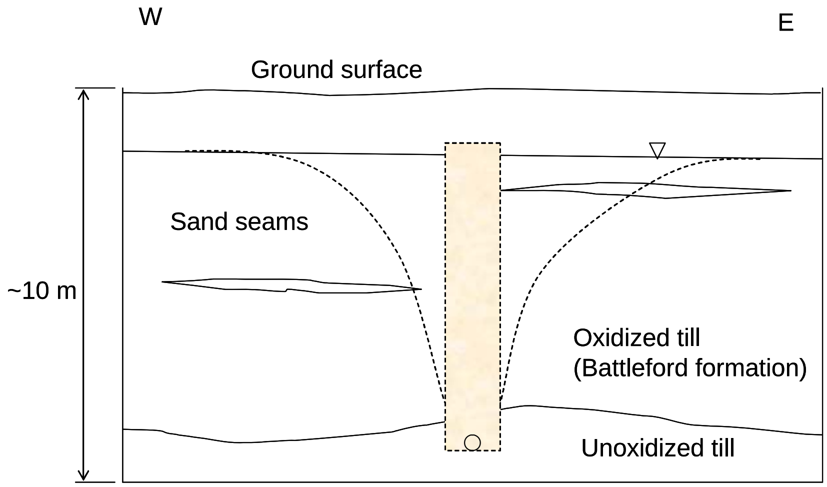

Figure 2.21 – Typical cross-section (showing groundwater drawdown post-construction).

2.7.2 Design

2.7.2.1 Vertical Alignment

The designed length of the French Drain was 1450 m. The vertical alignment of the French Drain was based on three primary factors:

1) the depth of the visibly fractured and/or oxidized till along the horizontal alignment,
2) the working range of readily available excavation equipment, and
3) the desire to have a minimum grade of 0.5% along the base of the French Drain.

The designed vertical alignment was set at or below the depth to unoxidized, unfractured till, which varied between 5.2 m and 9.8 m. The latter depth is considered extremely deep for an open excavation and was not believed to be achievable without significant sloughing. A standard hydraulic excavator can reach a maximum of 7.3 m. The decision to decrease the trench depth by removing surficial material was left up to the contractor. Design volume calculations assumed that a 1.07 m (42 inch) bucket would be utilized for the project.

The design included pump back wells, which were to be placed at natural low points in the unfractured till along the drain alignment. The trench was to be graded in the direction of the pump back wells to promote drainage, with inflection points located between each pair of pump back wells.

2.7.2.2 Backfill Design

The backfill designed for the French Drain is intended to act both as a filter and a drain. Proper design of the granular backfill allows passage of water from the pore space of the base soil while preventing movement of a significant number of base soil particles. The most important design feature of the French Drain backfill is its capacity to collect and carry water to the pump-back system at a low gradient and without pressure build-up. The difficulty in designing the granular backfill for the French Drain is a result of the conflicting requirements of the need for large pores to drain the backfill and small pores to restrict the movement of fines.

The design of the granular backfill (Figure 2.22) was designed using the recommendations from the National Engineering Handbook (NRCS, 1994). These recommendations are based on the work of Sherard and Dunnigan (1989), as detailed in Section 2.2. The base soils in situ were predominantly silty glacial tills, which fell under soil group 2 (contain between 40 and 85% fines). The maximum recommended D_{15} of the filter material for these base soils was 0.7 mm (Figure 2.22). A "design band" was created to allow for some variability within the filter media (for constructability). The width of the design band was to be kept relatively narrow to prevent the use of a gap graded filter. The width was limited to a factor of five between the minimum and the maximum D_{15} sizes and D_{60} sizes (i.e. maximum D_{15} / minimum D_{15} = 5). The remainder of the design band was set up so that the coefficient of uniformity (D_{60}/D_{10}) at the coarse end was 6 and the largest particle size possible was 75 mm. A maximum of 5% fine sized particles was allowed. Finally, to minimize segregation during construction, the D_{90} size was determined based on the approximate minimum D_{10} size. The maximum D_{90} size was 20 mm.

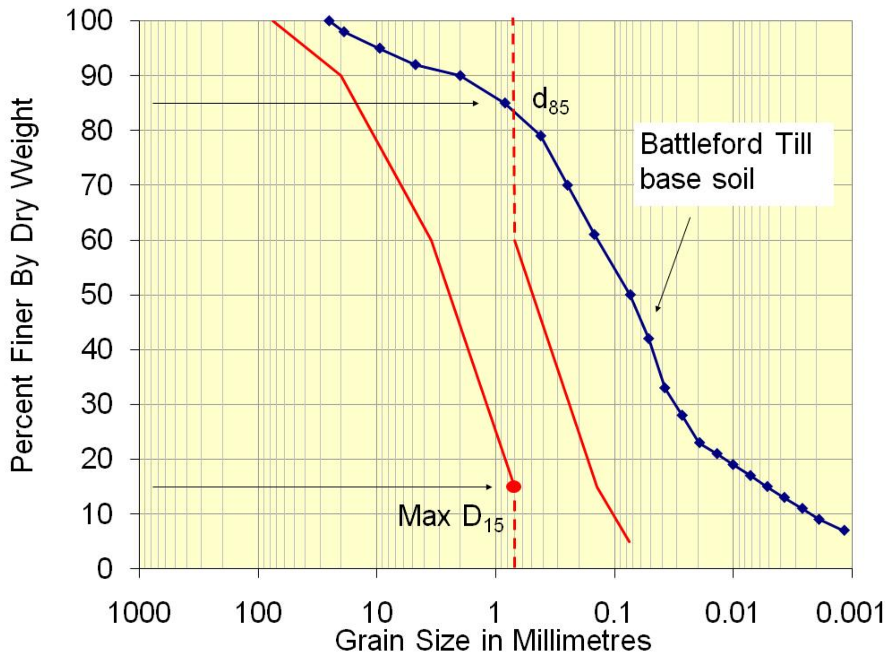

Figure 2.22 – French Drain backfill design.

A 1 m thick compacted till layer was designed to be placed as a cap for the French Drain backfill to minimize surface water infiltration into the drainage system. It was recommended that all depressions that develop along the French Drain due to settlement should be infilled to prevent pooling of surface water over the drain.

2.7.2.3 Basal Drainage Pipe Design

A drainage pipe was designed to be installed at the base of the French Drain to aid in obtaining positive drainage to the pump-back system. This design component was thought to be critical for the successful long-term performance of the drain.

Perforation of the pipe prior to installation was recommended. The design of the perforations of the drainage pipe was based on the need to form a filter cake between the pipe and the granular backfill. The purpose of the filter material is to restrict the movement of soil particles (retention criteria) into the pipe while allowing water to flow into the pipe (permeability criteria). The design must also have adequate lifespan (clogging resistance criteria). Three simple filtration concepts were used in the design process (Holtz et al, 1997).

1) The pipe will retain the drain aggregate if the size of the largest pore (perforation) is smaller than the coarsest 15% of the soil particles (D_{85}). As with graded granular filters, the larger particles of soil form a filter bridge over the hole, which in turn filters the smaller particles of soil, which then retain the soil and prevent piping.
2) The pipe holes will not blind or clog if the openings in the pipe are sufficiently large enough to allow smaller particles of soil to pass through the pipe perforations.
3) A large number of openings should be present in the pipe so proper flow can be maintained even if some of the openings become clogged.

Based on the above criteria and the grainsize distribution of the aggregate backfill, the recommended design included a minimum of four lines of 5 mm perforations at right angles (90^o offset) with a maximum 150 mm (6 inch) spacing between holes.

Flush ports were also included in the design. Flush ports provide surface access for chemical treatments (if necessary) and as a port for visual inspection of the pipe. They also allow the removal of accumulated sediment in the pipe.

2.7.2.4 Pump Back Well Design

The pump back well assemblies were to be comprised of 30 inch diameter heavy wall fibreglass casing. The screened section of the casing (below surface) was to be comprised of 40 slot (0.040 inch) horizontally slotted perforations. The wells were to extend 2 m below the designed trench base to allow for adequate submersible pump operation.

2.7.2.5 Monitoring System Design

A monitoring system was designed to be installed adjacent to the French Drain at several locations to monitor the effectiveness of the system. At several locations along the route, piezometer arrays were to be installed on the upstream and downstream sides of the French Drain. Piezometers were to be placed at 5 m, 15 m, and, where possible, 50 m from the French Drain. Piezometers were also to be installed within the French Drain backfill. The piezometers would be placed at the approximate depth of the French Drain (roughly 7.6 m or 25 ft).

2.7.3 Construction

2.7.3.1 Trenching

The Caterpillar 330 BL hydraulic excavator used for trenching had a maximum reach of approximately 7.5 m. Many sections of the drain required an excavation greater than this depth. As a result, most of the 1450 m line was benched down to obtain the desired depth and grade.

The bench was approximately 8 to 9 m wide. This allowed room for the excavator to manoeuvre within the bench as required. The depth of the bench varied from 1 to 3 m. In many cases, the bench was cut deeper so as to permit digging a shallower trench (a trench less likely to slough) or to remove deleterious surficial material.

A large trench box was used for a considerable portion of construction. The trench box was approximately 7 m high, 3.5 m long and 1.1 m wide (the owner had approved a wider excavator bucket than was used for the design). The box protected the basal pipe from damage due to sloughing and allowed for easier clean out of some sloughs. It was pulled along the trench several metres at a time after digging portions of the trench. Several drawbacks were associated with using this box:

1) It was heavy and difficult to advance along the trench bottom;
2) It was difficult to reach till material that had fallen inside or become stuck within the trench box; and
3) It was difficult to move in areas of tightly spaced mine infrastructure (power lines, brine lines, etc.).

A redesigned trench box would be recommended during future installations. During routine construction, the trench was advanced at a rate of approximately 6 to 10 m/hr. The rate of trench advancement was directly proportional to sloughing of the trench side walls and the presence of other obstacles such as rocks and mine infrastructure.

2.7.3.2 Pump Back Well Installation

The contractor believed that the pump back wells could be installed with traditional construction equipment rather than a drill rig. During installation of the first well, a hydraulic excavator "benched" down several metres to attain the required depth for the pump back well (11.6 m). The well was lowered into place by means of a crane. The basal drainage pipe was attached to the well 2 m above the base of the well before it was lowered into place. The rest of the pump back wells were installed in a similar fashion.

2.7.3.3 Basal Drainage Pipe

The basal drainage Sclair pipe was delivered to site in sections approximately 15 m long. Sections of pipe were fused together. The ends of each pipe were cleaned out, cut, heated, and then held together to form a tight bond. Specially designed equipment was used for this process. Photograph 2.1 shows a section of the trench with the pipe installed prior to placing granular fill.

The Sclair pipe used for the basal drainage pipe was well suited for the project and was installed as designed. The pipe performed well during routine construction; however, several factors caused the drainage pipe to kink during the project. Sloughing of the sidewalls onto the pipe often caused the pipe to be jerked at an angle causing a kink. The pipe manufacturers confirmed that if given time to recover, the pipe would retain the majority of its load bearing capabilities.

Photograph 2.1 – An open section of trench – prior to sand fill.

2.7.3.4 Granular Backfill

Proper grain size distribution for the backfill necessitated continual quality assurance during construction. More than 150 wash sieve tests were carried out to ASTM standards throughout the project. Some tests on the initial material brought to site did not meet the design specifications (with less coarse fraction than specified). The situation was remedied at the mixing plant before resuming hauling to site. Only three tests were recorded to be out of spec after that.

After the desired grade was achieved during trenching, granular backfill was placed over the basal drainage pipe (Photograph 2.2). Granular was deposited into the trench to within 1 m of final surface elevation. In many cases, the bench was deeper than one metre. In these instances, granular was placed to the top of the trench. The bench was then filled and compacted with till in lifts to within 1 m of final surface elevation. Finally, the section was retrenched to the depth of the granular and the trench was filled with granular, thus completing the French Drain.

Photograph 2.2 – Dumping granular material into the trench.

The till material excavated during construction of the bench and the trench required stockpiling. As the bench was excavated near surface, large quantities of organics and poor quality fill were encountered. Generally, the top metre of the excavation was hauled to designated spoil locations. Below the organic layer, the soil was primarily good quality till. Areas that exhibited a lot of sloughing typically contained sandier till or heavily fractured till (Photograph 2.3). Sand lenses were uncommon, but were noted when found.

Photograph 2.3 – Large excavation due to sloughing.

2.7.4 Monitoring

The French Drain is performing as intended over the majority of its length. Figure 2.23 shows a typical instrumented cross-section. Head levels are shown in a piezometer installed within the drain, along with head levels in wells installed at 5 m and 15 m offsets from the drain. Pre-pumping heads were relatively flat across the section, and showed the slight west to east groundwater gradient of the area. The figure shows an efficient head response to pumping. The piezometric head within the drain was below the completion depth of the piezometer. The piezometer was therefore dry. There appeared to be greater general drawdown in the wells upgradient the drain. There was also progressive drawdown with time, particularly in the wells installed nearer the drain (5 m both upgradient and downgradient).

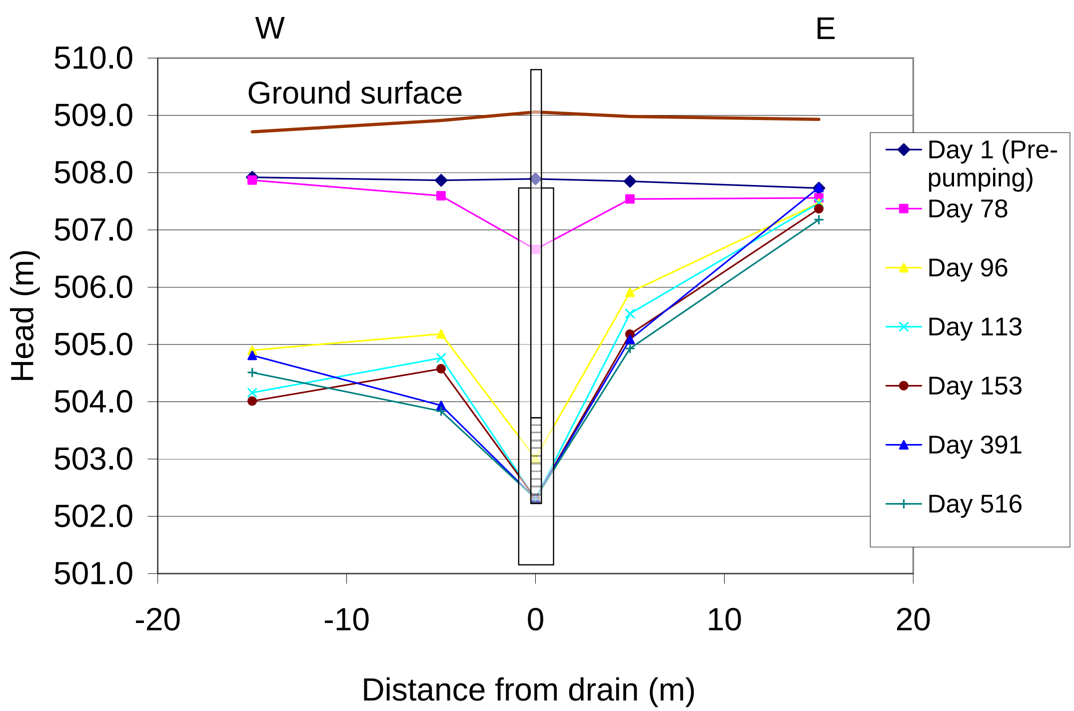

Figure 2.23 – Head levels perpendicular to the French Drain (typical instrumented cross-section).

2.8 Chapter Summary

The literature review described the development of granular drain design as well as the process of erosion and deposition of fines due to changes in salinity, the relative permeability loss in sands due to fines deposition, the modeling of this permeability loss, and a review of a recent drain installation. The information presented in this literature review seems to indicate that a drainage soil with a coarser "design band" than the current standard of practice would be acceptable for long-term environmental containment. This is true given the following conditions:

- if it can be shown that coarser soils minimize the impact of clogging, and
- as long as the mass of fines becoming entrained with groundwater flow does not cause base soil instability.

The first point will be investigated in the laboratory study based on this review. Questions to be answered include:

- How is the permeability of drainage soils affected by particle injection?
- Do more fines become trapped in a coarse soil or a fine soil?
- What impact does salinity have on deposition?

The question of base soil instability will not be answered with the laboratory study. However, a recommendation can still be made concerning the design of future drains/filters if we consider that *some* volume of fines will be transported into these drains, and even fine soil filters are not meant to stop silt and clay sized particles from passing the filter/base soil interface.

CHAPTER 3 TEST PROGRAM

3.1 Introduction

A laboratory program was undertaken to determine the rate and the permeability reduction in several granular soils that could potentially serve as a drain/filter layers. This goal was achieved by running flow-through column tests with both fresh and saline water influent solutions carrying a suspension of fine grained soils through granular soils.

3.2 Objectives

The primary objective of this test program was to evaluate the clogging potential of soils with different gradations when exposed to concentrations of fine soil under conditions of both fresh water and brine infiltration. In doing so, it was hypothesized that the design of granular drains exposed to low head conditions in brine environments could be amended. The primary objective was achieved with the following limitations. Firstly, the test program utilized one applied head condition for all tests. It is unclear whether the test results can be scaled up to field conditions. Secondly, the tests were set up in a manner that assumes the concentration of fine particles had already been released from within the base soil. Fine particles were added to an influent tank at a pre-determined concentration. This allowed a direct comparison of the effects of different types of fines on permeability reduction. However, this approach provided no insight to the relative erodibility of the fine soils in a natural subsurface environment exposed to brine then followed by fresh water. This approach also ignores the possibility of coarser particles (fine sand) from the base soil migrating into the drain soil, which could affect the filtering ability of the drain.

3.3 Materials

3.3.1 Sand

The "French Drain" sand used in the test program was well graded sand with some gravel and a trace amount of fines. The French Drain sand design band (Figure 3.1) provides the fine and coarse limits for a typical filter sand installed next to a silt or clay glacial till base soil. The maximum D_{15} size of the filter sand is the critical component of the design. The National Engineering Handbook (NRCS, 1994) recommends a maximum D_{15} particle size in the filter soil based on the proportion of fines (< 0.075 mm) in the base soil. The criteria for maximum D_{15} size are summarized as follows:

1) For soil group 1 (>85% fines), $D_{15} \leq 9 \times d_{85}$, but not smaller than 0.2 mm.
2) For soil group 2 (between 40% and 85% fines), $D_{15} = 0.7$ mm.
3) For soil group 3 (between 0% and 15% fines), $D_{15} \leq 4 \times d_{85}$.
4) For soil group 4 (between 15% and 40% fines), $D_{15} \leq (40 - A/40 - 15)\ (4 \times d_{85} - 0.7\ \text{mm}) + 0.7$ mm.

For soil group 3, the d_{85} can be based on the soil with no regrading. The A in the equation for soil group 4 is the percentage of fines in the base soil after regrading.

The sand used in the current laboratory test program fell in the centre of the design band (sand 1 in Figure 3.2). Four other filter sands were used in the current study (Figure 3.2). Sand 2 was a Unimin brand uniform medium sand (Uniform sand). This type of sand is often used as filter pack material for well installations. Sand 3 was a coarse, well graded sand with approximately 40% gravel sized particles (Coarse Graded sand). At the start of the testing program, two other filter sands were used (sands 3 and 4). The sands were premixed concrete sands and concrete gravels acquired from the materials lab at the University of Saskatchewan. The concrete sand was used in an attempt to match the material used by Reddi et al (2000 and 2005) and Hajra et al (2002). This sand was finer overall than the French Drain sand. It was determined that the concrete sand used in the previous studies closely resembled the French Drain sand used in the current study. The use of the concrete sand was then stopped prior to the main portion of the test program. The concrete gravel was determined to be too permeable (difficult to measure with the apparatus used) and exhibited insufficient repeatability for the testing requirements. It was thus replaced with the Coarse Graded sand.

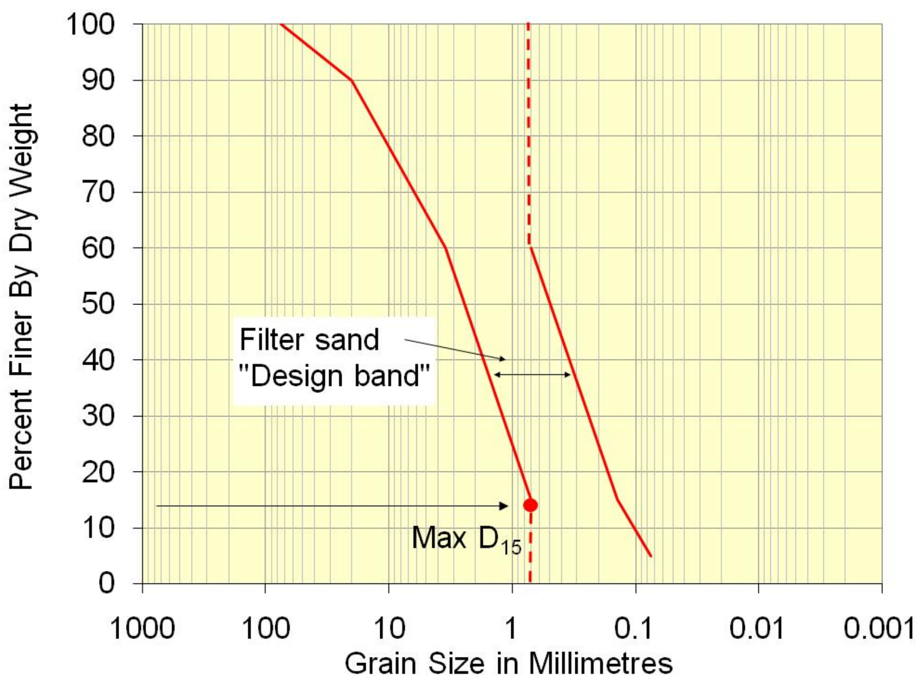

Figure 3.1– Filter sand design band for soil group 2 base soils (i.e. base soils with 40% to 85% fines).

Figure 3.3 shows the three sands used in the test program. Sand 2 (the Uniform sand) was commercially obtained and unaltered while sands 1 and 3 were developed in the laboratory by sieving large volumes of sand and gravel sized particles and mixing them into the desired gradation. The difference in appearance between the three sands is shown in Figure 3.4 through Figure 3.6. The D_{15} sizes of each filter material are 0.25 mm, 0.7 mm, and 0.9 mm for sands 1, 2, and 3, respectively.

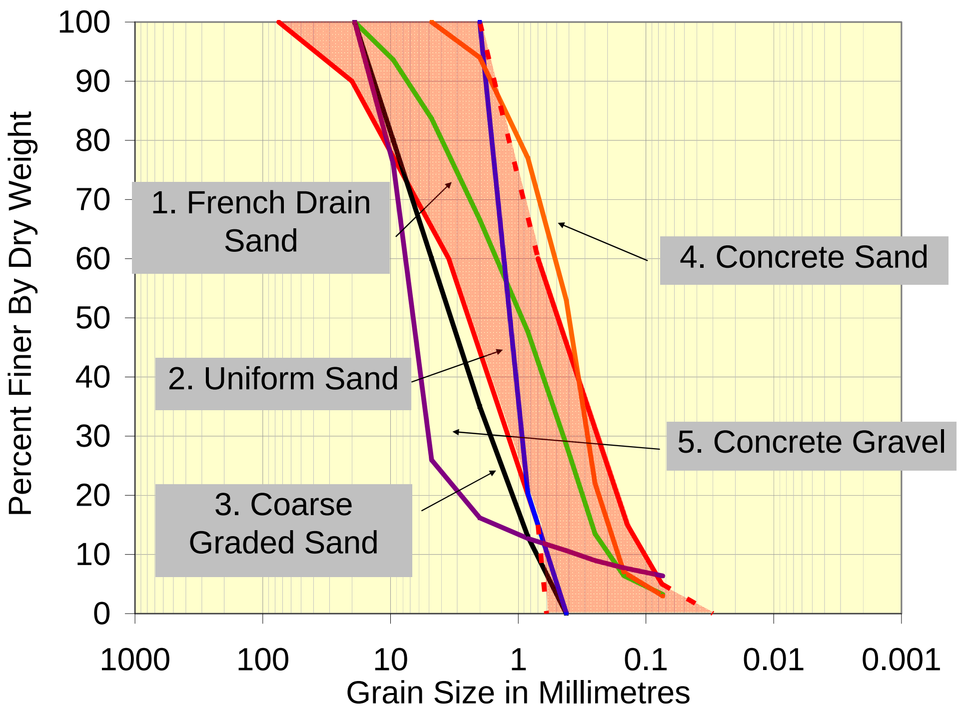

Figure 3.2 – Filter sands used during the laboratory study.

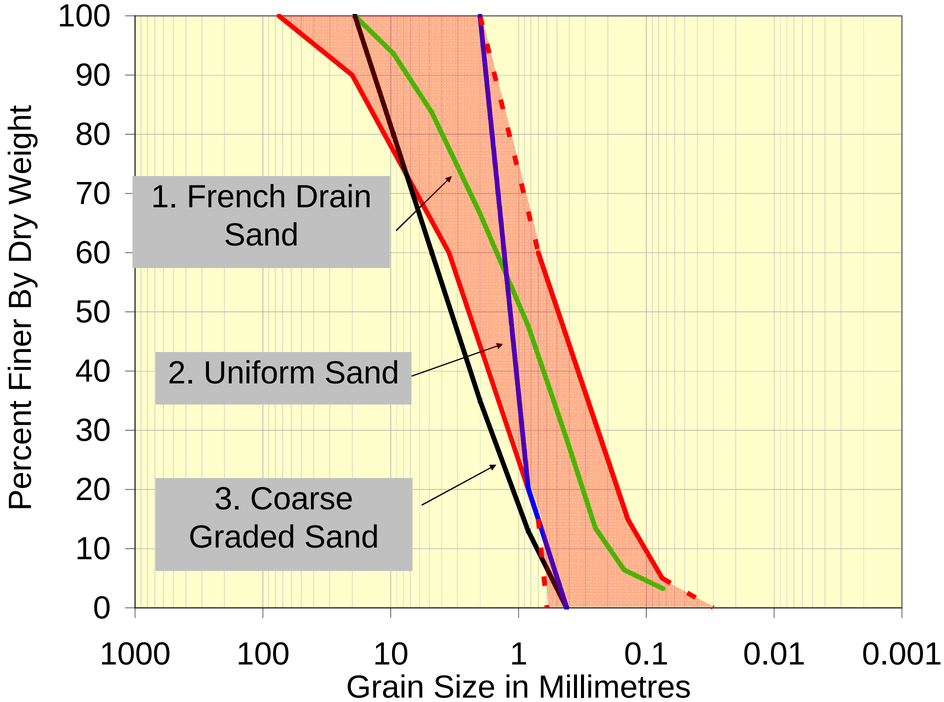

Figure 3.3 – Filter sands used in the test program.

Figure 3.4 – French Drain sand (sand 1).

Figure 3.5 – Uniform sand (sand 2).

Figure 3.6 – Coarse graded sand (sand 3).

The Hazen equation, which was developed from empirical tests on sandy soils, is a well known formula used to estimate the permeability of granular media. The equation uses the D_{10} value of the materials grain size distribution curve:

$$k = 100\ D_{10}^2 \tag{3.1}$$

where k is the permeability in cm/s and D_{10} is the sample particle size in mm that is greater than 10% of the sample by mass. Sometimes, a multiplication factor between 1.0 and 1.5 is added to the equation (Reddi, 1997). The Hazen equation was used for estimating the permeability of the drainage materials. The calculated values are shown in Table 3.1 (no multiplication factor was used).

Table 3.1 – Sand permeability calculated using the Hazen equation.

Granular material	D10 (mm)	k (cm/s)
French drain sand	0.2	0.040
Uniform sand	0.6	0.36
Coarse graded sand	0.7	0.49

The relative pore sizes of the three sands have a significant impact on their permeability. The particle size distribution of each sand was used to determine the range of pore sizes present, using the Arya and Paris (1981) method. The pore radius (r_i) was determined from the soil particle radius (R_i) considering packing of spherical particles and a scaling factor α that corrects for saturated soils:

$$r_i = R_i \sqrt{\frac{4e\, n_i^{1-\alpha}}{6}} \tag{3.2}$$

where n_i is the number of particles of a size class i and e is the void ratio:

$$n_i = \frac{3 w_i}{4\pi R_i^3 \rho_p} \tag{3.3}$$

where w_i is the mass of particles of a size class i and ρ_p is the particle density

$$e = \frac{\rho_p - \rho_s}{\rho_s} \tag{3.4}$$

Figure 3.7 shows that the majority of the pore water is contained in pores greater than about 80 µm in the two coarse sands. There is a significant amount of pore water in the same range of large pore sizes for the French Drain sand. A greater proportion of pore water exists in the smaller pores (ranging from about 32 to 80 µm) in the French Drain sand when compared with the coarser sands. Appendix A contains the complete tables of results.

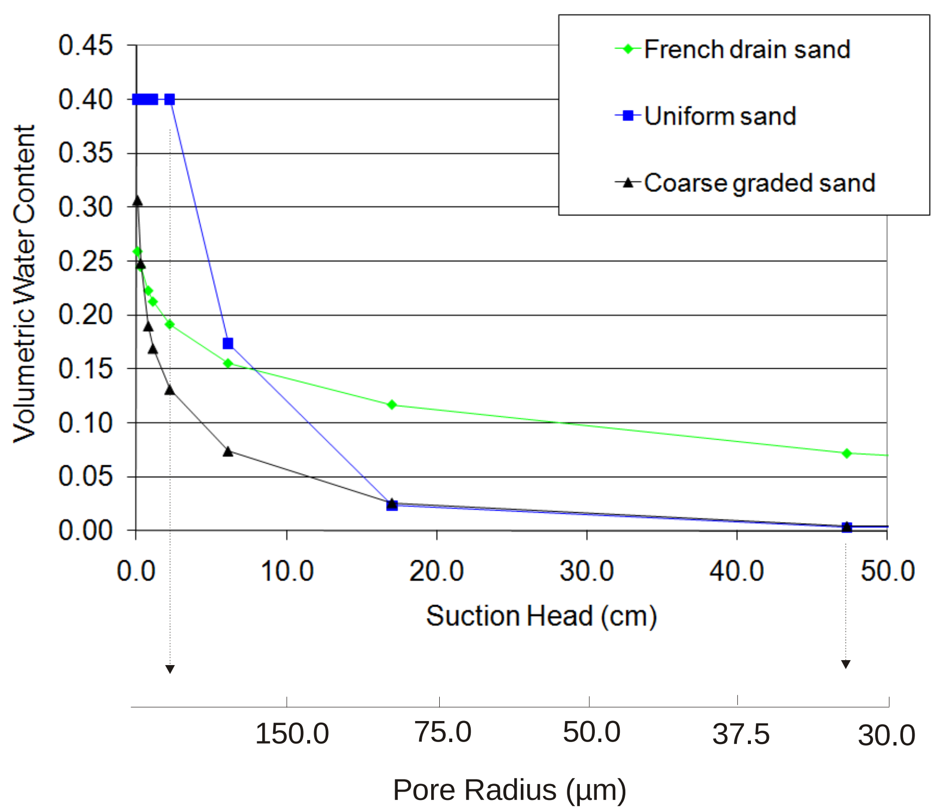

Figure 3.7 – Pore size distributions of the sands estimated using the Arya and Paris method.

3.3.2 Fines

Three mixtures of fine soils in water were injected into the filter sands during the test program. These consisted of a kaolinite clay, Battleford Till fines, and Regina Clay fines. The kaolinite clay was taken from a commercially bagged source. The Battleford Till fines and the Regina Clay fines were obtained by air drying, crushing, and sieving samples obtained from non-related site investigations. Only material finer than the #200 sieve (<0.075 mm) was used in the infiltrating fines concentrations.

A Malvern Mastersizer particle analyzer was used to find the particle size distribution (PSD) of the fine soils. The instrument uses laser diffraction and then analyzes light scattering data using electromagnetic field equations. The ISO standard ISO 13320 describes particle sizing by laser diffraction. A study by Wen et al. (2002) details the laser diffraction method (LDM) for fine soils and compares it to the sieve-hydrometer method. The authors recommend that LDM be adopted as the standard as discrepancies exist between the two methods depending on the soil type and specific size fractions. In the current study, particle size distributions were first found by mixing a small amount of each fine soil into tap water, which was fed into the analyzer. The procedure was then repeated using sodium chloride salt water mixed at the same concentration that was used in the test program. Past studies have shown that particle sizes are highly affected by salt concentrations (Hajra, etc.). The fine soils used in the current program were of clay and silt sizes (finer than 0.075 mm or 75 μm). The device returned the grain size distribution, the uniformity, and the specific surface area of the three fine soils. All results are shown in Appendix B. The following findings were observed:

- The fresh water D_{50} particle sizes were 18.1 μm, 27.3 μm, and 25.8 μm for the kaolinite, Battleford Till, and Regina Clay, respectively.
- The salt water D_{50} particle sizes were 16.7 μm, 26.9 μm, and 26.2 μm for the kaolinite, Battleford Till, and Regina Clay, respectively.
- The fresh water specific surface areas were 0.67 m^2/g, 0.44 m^2/g, and 0.47 m^2/g for the kaolinite, Battleford Till, and Regina Clay, respectively.
- The specific surface area for the kaolinite in salt water increased to 0.74 m^2/g but the others remained nearly the same.

The average particle sizes were larger than expected. Only 10% of the kaolinite material used appears to be of clay particle size (finer than 2 μm). The kaolinite used in the study by Reddi et al. (2000) had an average particle size of 2.6 μm. The other two fine soils used in the current program had a similar gradation and larger average particle sizes. The proportion of clay sized particles was found to be 5% in both the Battleford Till and the Regina Clay.

These results explain why there was so little change in the PSD when salt water was applied. The salt has an effect on the attractive and repulsive forces between clay minerals. Increasing the cation concentration results in a decrease in repulsive force (Craig, 1997). Clay particles tend to flocculate with a net attractive force, increasing the effective particle size. The salt seemed to have a minor influence since most of the particles in the fine soils were of silt sizes. A second contributing factor may have been that tap water contains some cations, causing a certain degree of flocculation prior to the addition of salt. A better indicator of the salinity effect may be the change in the distribution of clay sized particles. In the kaolinite results, we see that the percentage of particles in each size range below 2 μm has increased with the salinity (as expected). The clay particles (more specifically, the flocs of clay particles) in the other two soils, however, showed no size change with increased salinity.

The measured specific surface area of the soils indicates that the activity of the clay minerals is low. Regina Clay in particular is known to contain high swelling montmorilonite clays with specific surface areas in the range of 900 m^2/g. Kaolinite is known as a low activity (non-swelling) clay, with specific surface areas that are much smaller. It appears that the samples used in the program contain a small amount of high activity minerals.

3.4 Laboratory Setup - Apparatus

The laboratory setups used in the study were based on the laboratory program apparatus used in the work of Reddi et al (2000 and 2005) and Hajra et al (2002). Two identical laboratory setups were assembled for the current study. A photograph of one of the setups is shown in Figure 3.8. The apparatus used for the laboratory tests consisted of a vertical column (255 mm high, 115 mm diameter) with nine ports, spaced along the side of the column. Figure 3.9 shows a cross-section of the column used, with the height of each port in millimetres, from the base of the granular sample. The ports were attached to manometer tubes in order to measure head at various elevations within the column. A continuous piece of geotextile was placed along the inside wall of the column in order to filter water entering each manometer tube. A wire screen was placed at either end of the granular sample. The screen openings were approximately 0.5 mm. The bottle shown in Figure 3.8 was fed from an influent tank on the floor by a peristaltic pump. A magnetic stirrer was used to ensure fine particles remained in suspension in the bottle. The overflow port near the top of the bottle ensured the condition of constant applied head. A second tube connected the bottle to the column. An applied head of 27 cm was one of the constants of the test program.

Figure 3.8 – Laboratory setup 1 of 2 (constant applied head conditions).

Preliminary testing involved made use of the same test apparatus. The main difference was the application of a constant flow rate through the column (Figure 3.10). The setup was simple, with the peristaltic pump delivering flow directly from the influent tank to the column. The main difficulty with this apparatus was the large pressures that developed within the sample. The manometer tubes did not extend high enough to allow for sufficiently long test periods. Constant applied head conditions were also deemed to be more representative of field conditions. The constant flow test setup was thus abandoned.

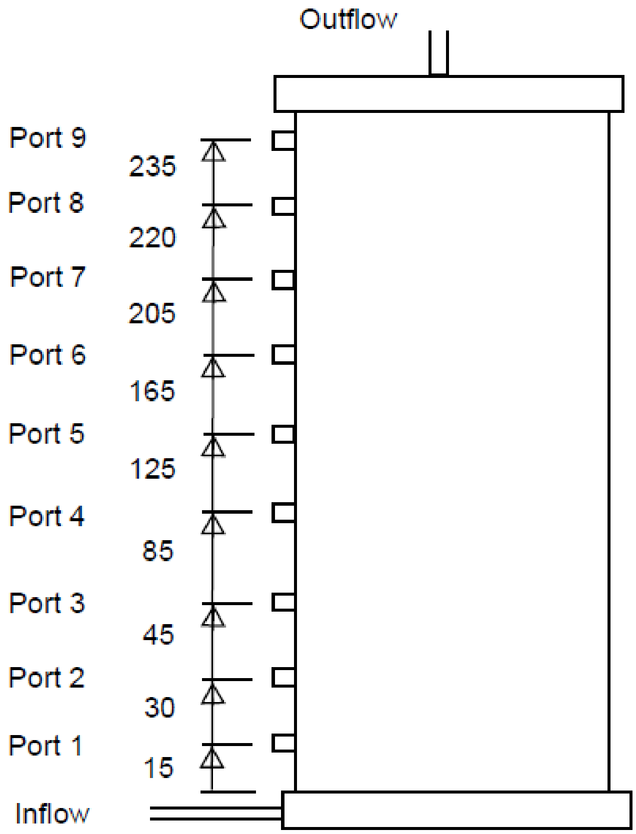

Figure 3.9 – Laboratory column test apparatus cross-section.

The main differences between the apparatus used in this study and those used in previous studies (Reddi et al, 2000 and 2005; Hajra et el, 2002) were as follows. Previous studies used a smaller sample size (64 mm in length with a 76 mm diameter), a peristaltic pump with programmable flow rates, and a differential pressure transducer across the column. A data logging system recorded changes in head. In the current study, head changes were measured at different elevations within the column. All data was recorded manually and transferred to spreadsheets.

Figure 3.10 – Preliminary laboratory setup (constant flow conditions).

3.5 Test Procedure

The test procedure was modified throughout the initial stages of the test program. The constant flow test results constitute a minor portion of the study findings. The results helped to develop procedures for the remainder of the test program. As such, all test procedures are detailed here.

All tests performed following the initial constant flow tests used a constant head of water applied to the inflow port. A series of constant head calibration runs were conducted, in order to finalize the laboratory setup and test materials. This was followed by tests in which permeability recovery was attempted through the flow of fresh and salt water without suspensions of fines. The final test procedure focused on the rate and amount of permeability reduction, and fines breakthrough and deposition characteristics.

3.5.1 Constant Flow Test Procedure

Column tests conducted under constant flow conditions helped to develop an understanding of the varying rates of permeability reduction depending on sand gradation. The concrete sand and the Uniform sand were used in these preliminary tests. The test procedure is outlined as follows. The sand was poured into the column with wire screens placed on either end of the sample. The manometer tubes were connected to each of the nine ports on the side of the column. A flow of tap water was initiated from a tank (pail) into the base of the column with the use of a peristaltic pump. A constant flow rate of 155 mL per minute was used.

Total head at several ports (the top and bottom ports, at a minimum) were recorded by noting the elevation of the water level in the associated manometer tubes. The concentration of kaolinite clay added to the influent tank during these initial tests was not pre-determined. The intention was to keep the test duration short. A concentration of 5 grams per litre of kaolinite clay was used in the first test for each of the two sands. Two other concentrations of clay were used for each sand in subsequent tests. The tests ran from 9 to 30 minutes each.

3.5.2 Constant Head Calibration Test Procedure

Four granular soils were used in the initial tests, including concrete sand, French Drain sand, Uniform sand, and concrete gravel. For each test, the granular sample was placed in the column in the same manner as the constant flow tests. Fresh tap water was used at the beginning of each test. Flow was directed from the influent tank to the bottle by a peristaltic pump, then through the column from bottom to top. The effluent was collected in a separate container and was not reintroduced to the system. The permeability (k) of the sample was determined by relating the flow rate through the sample to the hydraulic gradient ($i = \Delta h/\Delta l$) across the sample using Darcy's law:

$$Q = -k\frac{\Delta h}{\Delta l}A \tag{3.5}$$

where Q is the flow rate (cm^3/s), k is the coefficient of permeability (cm/s), Δh is the difference in head (cm) across the length of interest, Δl (cm), and A is the cross-sectional area of the column (cm).

The initial stage of each test was essentially a constant head permeability test. The flow rate was determined by collecting effluent in a beaker over a timed interval. Heads within the sample were then recorded for ports 1, 4, 6, and 9. This process was repeated several times until flow stabilized, at which point the initial permeability of the sample (k_o) was determined. In this context, the entire sample is considered to be between ports 1 and 9. Test results that refer to the influent end and effluent end of the sample indicate measurements between ports 1 and 4, and 6 and 9 respectively. Reddi et al (2005) calls the period prior to flow stabilization the self-filtration process, in which particles within the sample become rearranged with the flow. During this process, no fine particles were added to the influent. Reddi's testing showed that self-filtration alone could reduce the permeability of a sample by more than 70% after about 200 pore volumes. It was determined that "[t]he flow rates or gradients used in the experiments and duration used for permeation govern the hydraulic conductivity measurements, particularly in the case of graded soils" (Reddi et al, 2005).

Once flow stabilized, a concentration of 5 g/L of kaolinite clay was added to the influent tank. A submersible pump was used to maintain the suspension of fines in the tank. Flow rate and head measurements were recorded throughout the remainder of each test. These initial tests ran for less than six hours. Following each test, the sample was split into three portions (influent end, centre, and effluent end) and wash sieve tests were conducted.

3.5.3 Permeability Recovery Test Procedure

The tests that followed these initial constant applied head tests focused on permeability recovery following clogging. The concrete gravel was dropped for these tests. The experiments were conducted in the same manner as before, with the following additions:

- turbidity measurements,
- salt in the influent water, and
- an attempt at permeability recovery.

The turbidity of the effluent was determined after each measurement of flow rate (grab samples were tested in a turbidimeter). In some of the tests, salt was used in the influent. A concentration of 0.5 molar NaCl was added to the influent tank either at the start of the test, or following the self-filtration portion of the test (i.e. added at the same time as the fines). Again kaolinite fines were injected into the column at a constant concentration for several hours. The only basis for stopping this portion of the test was that the rate of permeability reduction had slowed (later tests ran for much longer time periods and showed higher rates of permeability reduction). The constant applied head of 27 cm was not altered throughout each test. Following the clogging portion of the tests, the samples were subjected to periods of water inflow without added fines. First, a 0.5 M NaCl concentration influent was sent through the sample. This was followed by an influent of fresh tap water. The effects on permeability and turbidity were then measured. The tests ran for 23 to 82 hours each.

3.5.4 Final Test Procedure

The final test procedure was determined based on the calibration and permeability recovery test runs. An emphasis was placed on comparing the rates of permeability reduction and not on permeability recovery following clogging. Most tests were run until the permeability stopped decreasing (constant in two consecutive readings). Test times ranged from 7.5 hours to more than 38 hours, once the fine particles were added to the influent. A second constant applied head apparatus was developed. The concrete sand was dropped from the program and the Coarse Graded sand was added.

Battleford Till fines and Regina Clay fines were added to the testing program. A new influent fines concentration of 1 g/L was added to the program. Part of the purpose of measuring the turbidity of the effluent was to attempt to quantify fines retention in the samples with time. The high concentration of 5 g/L of fines in the influent resulted in influent turbidities greater than 1000 NTU. Any turbidity greater than 1000 NTU was not quantifiable as it was above the measurable range of the turbidimeter used. The lower concentration allowed for measurable influent turbidities in the Battleford Till fines and Regina Clay fines solutions.

Another method of quantifying fines flow through the samples was to develop breakthrough curves. Effluent fines concentrations were measured periodically throughout some of the tests. These measurements were taken by collecting a known volume of effluent, drying it, then weighing the mass of solids. A correction for the salt concentration was required for those tests in which 0.5 M NaCl was used in the influent. The concentration of salt was assumed to be unchanged during flow through the sample.

The percentage of fines deposited within the layers of each sample was of interest. Building on ideas developed in the calibration tests, the samples were split into six equal portions following each test. These samples were then dried, weighed, washed of fine particles, then dried and weighed again. This produced a percentage of fines (by mass) within each layer of the columns.

CHAPTER 4 PRESENTATION AND DISCUSSION OF TEST RESULTS

4.1 Introduction

Chapter 4 presents the results of the laboratory program. All test data is shown in Appendix C. Section 4.2 presents the results of the constant flow tests that were performed at the beginning of the test program. Section 4.3 describes the first constant head results. The section details the tests performed to calibrate the test setup and finalize the test materials, along with the tests that measured permeability recovery following clogging.

The final procedure test results are presented in Section 4.4. The section first describes the "self-filtration" portion of the tests, followed by a presentation of the permeability reduction test results with both tap water and salt water as the permeants. The effect of salt water on permeability reduction is discussed by directly comparing tap water tests with kaolinite to salt water tests with kaolinite. Further graphs illustrate the effects of mass loading on permeability reduction. Finally, the section presents the fines capture within the column and fines breakthrough in the effluent. Again, salinity and the type and concentration of fines is compared and discussed.

Section 4.5 presents a comparison of the current results with previous investigations in the literature. The discussion compares the performance of fine sand drains with coarse drains and attempts to show that a coarse drain sand is a better alternative to a fine sand, in areas where the stability of the base soil will not be affected.

4.2 Constant Flow Tests (Preliminary Test Results)

Constant flow tests were conducted at the start of the test program to determine the approximate concentrations of fines required to reduce the permeability of sands over a short period of time. Concrete sand and Uniform sand were permeated with kaolinite in these tests. The concentrations of kaolinite clay used were much higher than those used by Reddi et al. (2000), in order to keep test durations short. Clay concentrations varied from 5 g/L to 20 g/L for the concrete sand tests and from 5 g/L to 80 g/L in the Uniform sand tests. Reddi et al. (2000) used a maximum of 1 g/L clay in suspension.

Head levels increased with time at the influent end upon clay injection in the concrete sand. Head in the last 3 manometer tubes (at the effluent end) did not change or changed minimally throughout the tests. This indicates that many clay particles likely became trapped near the influent end of the sand. Some clay travelled through the sample, as indicated by a cloudy effluent.

Table 4.1 shows the data for the test run on concrete sand using 5 g/L kaolinite clay. The flow rate, Q, was kept constant (155 mL/min or 2.6×10^{-6} m^3/s) during the test. The initial reading (time = 0) was taken just prior to the addition of fines to the influent. The "Manometer Readings" section shows the head readings near the inflow and outflow ends of the column. Ports 1 and 9 were 22 cm apart (1.5 cm and 23.5 cm from the base of the column, respectively). The difference in total head (delta h) divided by the difference in elevation head, delta l (22 cm) equals the hydraulic gradient, i. The permeability, k, was calculated for each set of readings using Q, i, and the constant cross-sectional area, A (8.16×10^{-3} m^2). Finally, each permeability reading is presented as a percentage of the initial permeability, k_o. The initial permeability in these constant flow rate tests differs from k_o in the remainder of the test program. In these tests, tap water was directed through the samples for only a short period of time prior to the addition of fines in the effluent. There was no time for "self-filtration" that may have resulted in a loss of permeability due to the rearrangement of particles.

Figure 4.1 graphs the 5 g/L test run shown in Table 4.1. The permeability is plotted on the ordinate (in cm/s). The volume of flow through the sand, measured in pore volumes, is plotted on the abscissa. The dotted line added to the trendline projects a further decrease in permeability, should the test have been continued.

Table 4.1 – Test run (5 g/L kaolinite clay in concrete sand).

K_o (cm/s) =	3.3E-02
Area (m2) =	8.16E-03
Pore Volume (mL) =	808
delta l (cm) =	22

Time (after adding fines to influent)			Flow rate readings		Manometer readings						
Time (minutes)	Time interval (minutes)	Pore volumes	Volume collected (mL)	taken to collect (s)	Port 1 head (cm)	Port 9 head (cm)	delta h (cm)	Q (m3/s)	i [(Port 1 - Port 9) / 22]	k (cm/s)	% of K_o
0	-1 to 0	0.0	155	60	52.1	31.0	21.1	2.6E-06	0.96	3.3E-02	1.00
1	1 to 2	0.2	155	60	51.5	31.0	20.5	2.6E-06	0.93	3.4E-02	1.03
3	3 to 4	0.6	155	60	52.1	31.0	21.1	2.6E-06	0.96	3.3E-02	1.00
10	10 to 11	1.9	155	60	53.3	31.0	22.3	2.6E-06	1.01	3.1E-02	0.95
17	17 to 18	3.3	155	60	57.2	31.0	26.2	2.6E-06	1.19	2.7E-02	0.81
20	20 to 21	3.8	155	60	59.4	31.0	28.4	2.6E-06	1.29	2.5E-02	0.74

Table 4.2 shows the data for the test run on Uniform sand using 5 g/L kaolinite clay. The measured gradient is much lower in the Uniform sand test run than in the concrete sand test run, as the difference in total head between ports 1 and 9 (delta h) is much smaller with the Uniform

sand. Each permeability reading is presented as a percentage of the initial permeability, k_o. Figure 4.2 graphs the 5 g/L test run shown in Table 4.2.

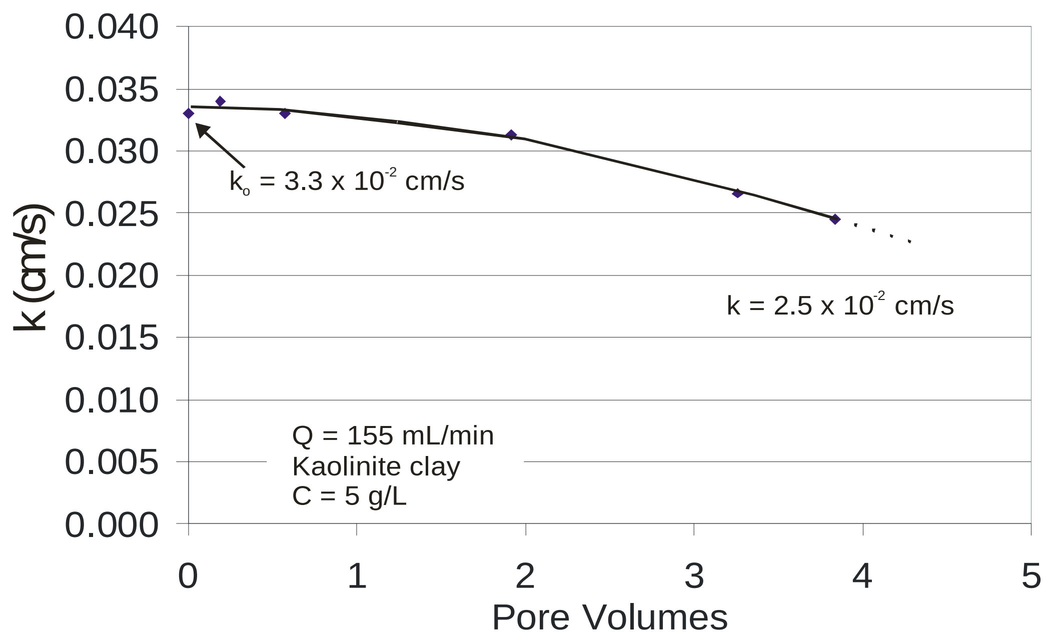

Figure 4.1 – Constant flow tests on concrete sand (permeability vs. pore volumes).

Table 4.2 – Test run (5 g/L kaolinite clay in Uniform sand).

K_o (cm/s) =	8.7E-01
Area (m2) =	8.16E-03
Pore Volume (mL) =	1059
delta l (cm) =	22

Time (after adding fines to influent)			Flow rate readings		Manometer readings						
Time (minutes)	Time interval (minutes)	Pore volumes	Volume collected (mL)	taken to collect (s)	Port 1 head (cm)	Port 9 head (cm)	delta h (cm)	Q (m3/s)	i [(Port 1 - Port 9) / 22]	k (cm/s)	% of K_o
0	-1 to 0	0.0	155	60	30.9	30.1	0.8	2.6E-06	0.036	8.7E-01	1.00
2	2 to 3	0.3	155	60	30.9	30.1	0.8	2.6E-06	0.036	8.7E-01	1.00
5	5 to 6	0.7	155	60	30.9	30.1	0.8	2.6E-06	0.036	8.7E-01	1.00
10	10 to 11	1.5	155	60	30.9	30.1	0.8	2.6E-06	0.036	8.7E-01	1.00
15	15 to 16	2.2	155	60	30.9	30.0	0.9	2.6E-06	0.041	7.7E-01	0.89
20	20 to 21	2.9	155	60	30.9	30.0	0.9	2.6E-06	0.041	7.7E-01	0.89
25	25 to 26	3.7	155	60	30.9	30.0	0.9	2.6E-06	0.041	7.7E-01	0.89
30	30 to 31	4.4	155	60	30.9	29.9	1.0	2.6E-06	0.045	7.0E-01	0.80

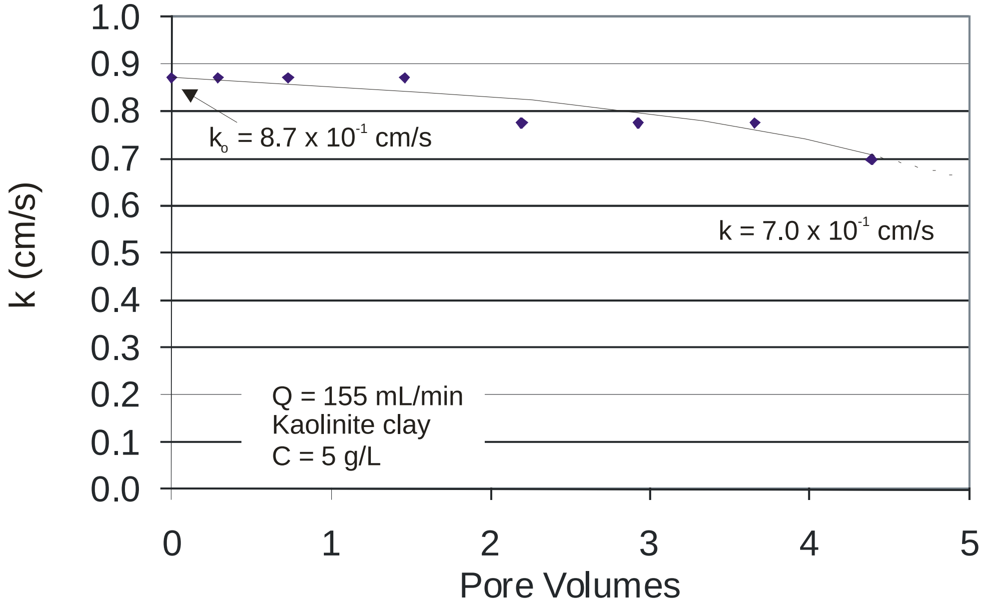

Figure 4.2 – Constant flow tests on Uniform sand (permeability vs. pore volumes).

Figure 4.3 shows the results of all three concrete sand test runs with kaolinite. The ratio of the measured hydraulic conductivity to initial hydraulic conductivity (k/k_o) is plotted on the ordinate. Again, the volume of flow through the sand, measured in pore volumes, is plotted on the abscissa. Higher concentration clay suspensions decreased the permeability in the sand at a greater rate. The ratio of k/k_o decreased to 0.39 after less than 2 pore volumes of flow for the 20 g/L suspension. The effluent was visually observed to be cloudy during the tests.

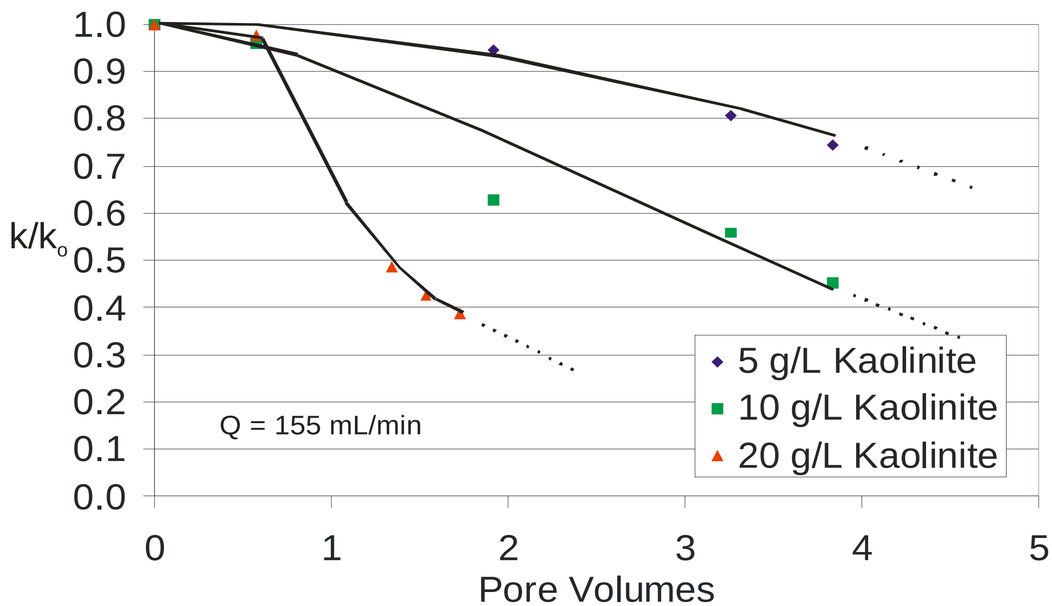

Figure 4.3 – Constant flow tests on concrete sand.

The Uniform sand required higher concentrations of kaolinite to achieve the same level of permeability reduction (Figure 4.4). More clay particles were able to flow through the Uniform sand, as the effluent cloudiness was visually observed to be greater than in the case of the concrete sand. Permeability is reduced more slowly in the Uniform sand (than the concrete sand) at low concentrations of clay infiltration (5 g/L). The figure also shows that a suspension of 80 g/L of clay injected into the Uniform sand reduces the relative permeability more slowly than 20 g/L of clay injected into the concrete sand.

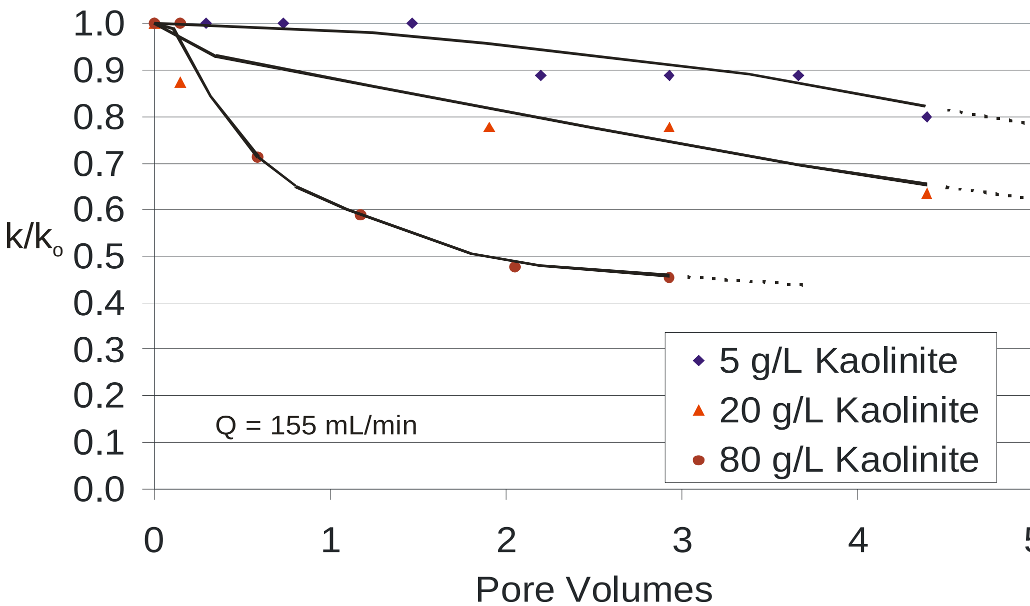

Figure 4.4 – Constant flow tests on Uniform sand.

4.3 Constant Applied Head Tests

The initial constant applied head tests were run with the intention of establishing a repeatable test procedure and to select the test materials for the program. Following this, tests were run to determine the achievable level of permeability recovery following clogging. Turbidity testing was introduced as a means of quantifying the rate of fines flow through the samples. The effect of salt water as a permeant was also measured on sample permeabilities and the movement of fines.

4.4 Calibration Results

Initial constant head tests were performed with kaolinite fines on concrete sand, French Drain sand, and Uniform sand. Table 4.3 shows one reading from each of the three tests. The readings provide a snap shot of each test following the self-filtration portion of the test and prior to the addition of kaolinite fines. Thus the readings provide the initial permeability, k_o of the each test sample. The flow rate measurements provide an indication of the relatively large permeability of the Uniform sand.

Additional manometer readings were taken on the finer sands (concrete sand and French Drain sand), which were not taken during the constant flow tests. This allows for the presentation of hydraulic gradient, i, and permeability, k_o, at the influent end (port 1-4) and effluent end (port 6-9) of the column, for those tests.

Table 4.3 – Trial constant applied head test readings, following self-filtration.

K_o (cm/s) = 1.3E-02
Area (m^2) = 1.04E-02
delta l (cm) = 22

Filter sand	Pore volumes	Flow rate readings: Volume collected (mL)	Flow rate readings: taken to collect (s)	Manometer readings: Port 1 head (cm)	Manometer readings: Port 9 head (cm)	Manometer readings: delta h (cm)	Q (m3/s)	i [(Port 1 - Port 9) / 22]	k_o (cm/s)
Concrete sand	0.0	129	120	46.7	29.1	17.6	1.1E-06	0.800	1.3E-02
French Drain sand	0.0	110	120	50.0	28.7	21.3	9.2E-07	0.968	9.1E-03
Uniform sand	0.0	250	60	30.5	29.5	1.0	4.2E-06	0.045	8.8E-01

The relative permeability decrease (i.e. k/k_o ratio) measured in the three sands due to inflow of tap water with kaolinite fines suspensions is shown in Figure 4.5. In this figure, the ratio of the measured hydraulic conductivity to initial hydraulic conductivity (k/k_o) over the whole column has been plotted against time. The Uniform sand had the fastest rate of permeability reduction. This is likely due to the significantly greater volume of fines through the Uniform sand sample. Under the given head conditions, the initial flow rate (at the introduction of fines) through the Uniform sand was 250 mL per minute. Initial flow rates through the concrete sand and the

French Drain sand were 65 mL/min and 55 mL/min, respectively. The more common method of data presentation in the literature has been permeability reduction versus the number of pore volumes of flow through the sample. This allows for the upscaling of laboratory results to field cases, where flow volumes and travel times are much greater (Reddi et al. 2000).

The same data is presented in a plot of k/k_o vs. pore volumes in Figure 4.6. From this figure, it can be seen that the volume of flow required to achieve the same degree of permeability reduction is significantly higher with the Uniform sand. The Uniform sand required 2 to 3 times more relative flow volume than the finer drain materials. This figure also shows that the three sands retained less than 35% of their initial permeability at the end of the tests.

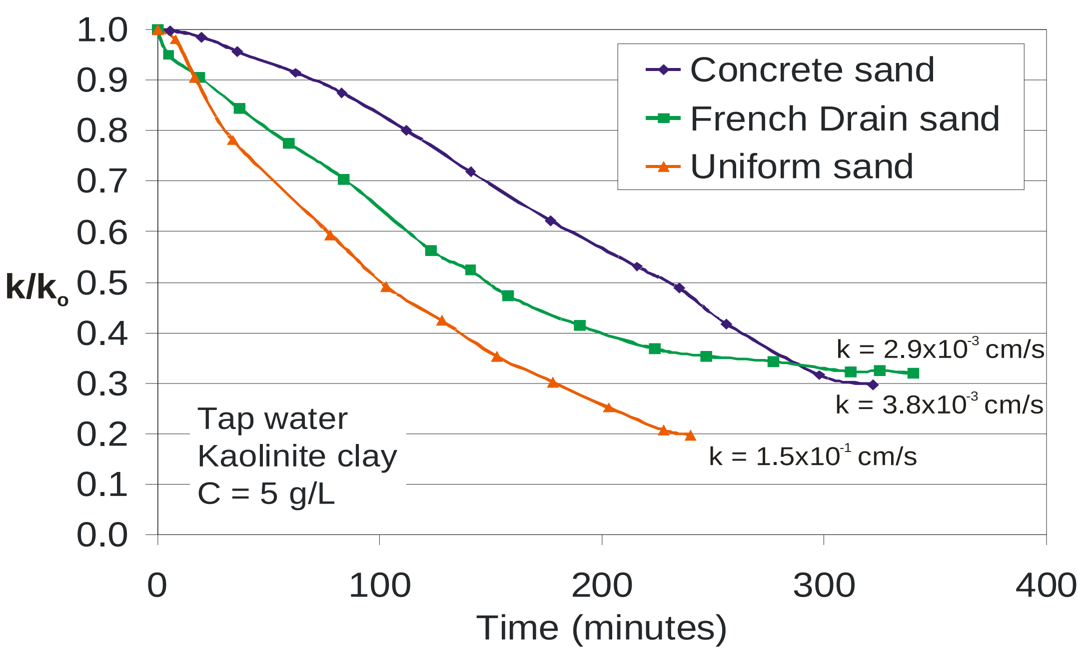

Figure 4.5 – Permeability reduction across the column vs. time (tap water).

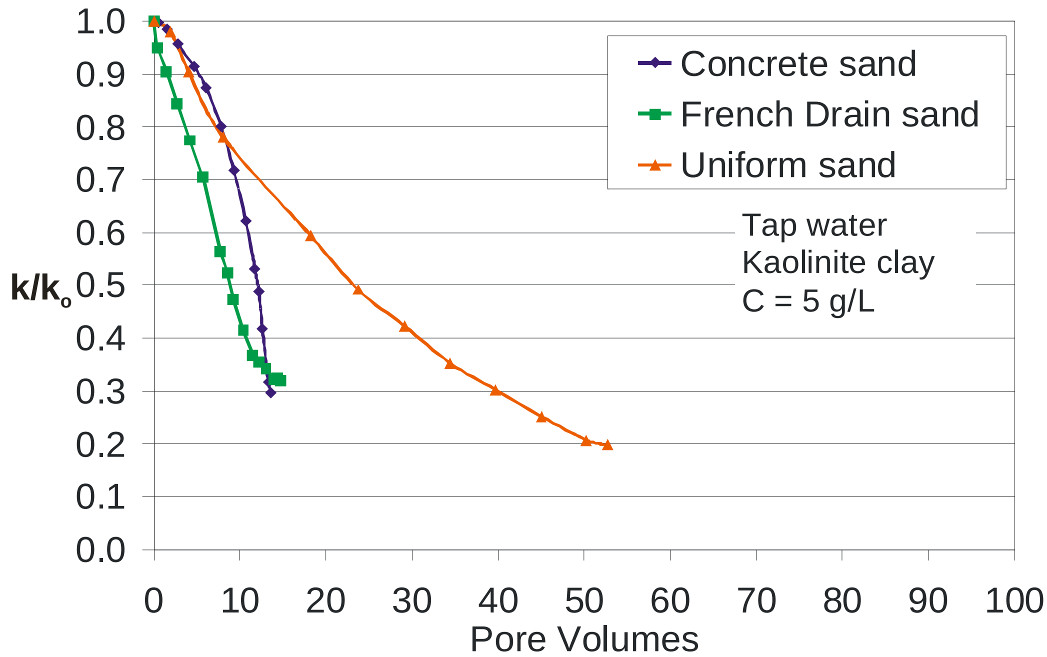

Figure 4.6 – Permeability reduction vs. pore volumes (tap water).

Figure 4.7 displays more detailed results of the test run performed on the French Drain sand (shown in Figure 4.5 and Figure 4.6). The figure compares permeability reduction at the influent and the effluent ends of the sample, as well across the whole sample. The reduction in permeability at the influent end (between ports 1 and 4) appears to be more rapid than at the effluent end (between ports 6 and 9). The overall drop in permeability is greater at the influent end than across the whole sample, and significantly greater than the drop in permeability at the effluent end. This indicates that fines likely became trapped in pores at the influent end of the sample first. This resulted in a decrease in pore size of the once homogeneous filter material, and thus an increase in the differential head in that area of the column.

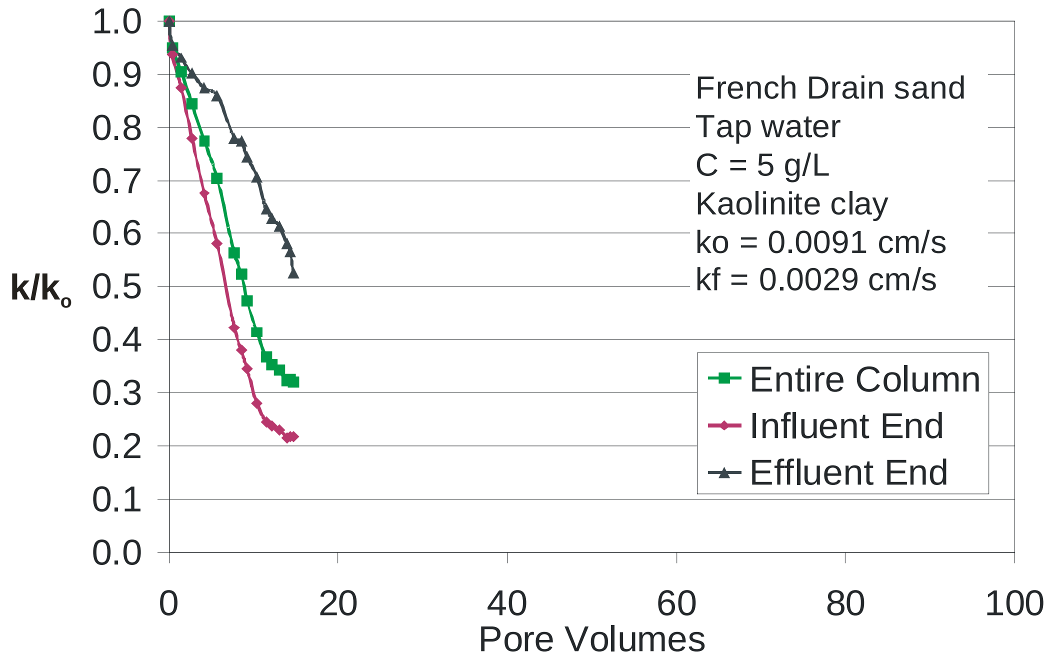

Figure 4.7 – Permeability reduction vs. pore volumes over portions of the sample.

4.5 Permeability Recovery Test Results

Drains installed as active barrier systems surrounding tailings areas may be subjected to periods of fines infiltration followed by extended periods of flow where the concentration of suspended solids in the pore stream is negligible. Figure 4.8 and Figure 4.9 show the results of a laboratory experiment on French Drain sand designed to examine drain permeability recovery. This test was the first to incorporate turbidity measurements. Effluent grab samples were taken periodically over the course of the test. A turbidimeter returned the values shown in the figures. Grab samples were discontinued during the test when it was clear that the effluent turbidity was greater than 1000 (the maximum turbidimeter reading). This procedure was continued in the remaining tests in the program.

In this test, the sample was subjected to the inflow of kaolinite clay suspensions in a 0.5 M NaCl brine solution. The sample permeability was reduced to 34% of its original value during this phase of the test (Figure 4.8). During the clogging portion of the test, the sample influent containing kaolinite in suspension had a turbidity greater than 1000. Many of the fines were able to flow through the soil sample; as indicated by the high effluent turbidities shown in the early portion of the test.

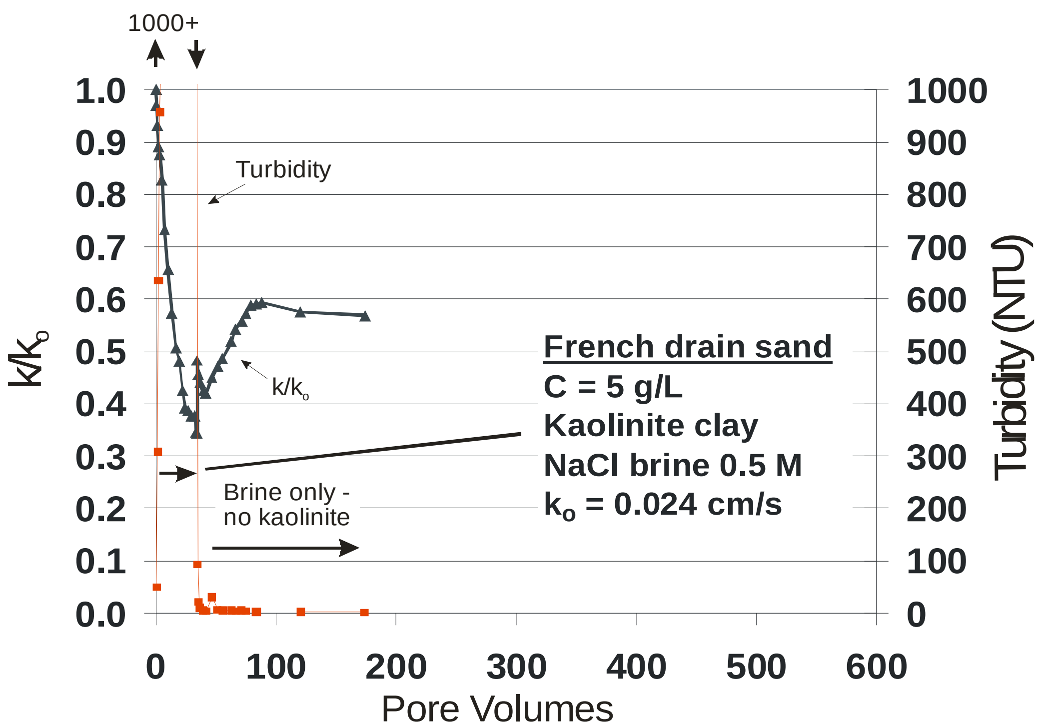

Figure 4.8 – Sand 1 Permeability recovery experimental run, Part 1.

The flow was then switched to 0.5 M NaCl brine without fines. The same head condition was applied, and the flow was directed through the sample in the same direction. The permeability immediately increased, dropped, and then rose steadily to 59% of the original sample permeability before leveling off near 57%. The flow of brine (without fines) through the sample created a reduction of the measured turbidities to nearly zero, though fines were still present in the column. Turbidity remained negligible until flow was switched to tap water. This shows evidence of the attractive surface potential energy between the sand and the fines.

The third phase involved feeding tap water though the sample under the same head conditions. The results are shown in Figure 4.9. Permeability spiked to 85% with the tap water flow. The permeability then fell and was followed by a trend upward with time. A permeability spike is the opposite effect of that found with fresh water flow through water sensitive sandstones (Khilar and Fogler 1984). The flow of tap water caused the remaining fines within the column to disperse. The tap water removed the attractive surface potential energy created by the brine. Effluent turbidities increased drastically with tap water flow before falling back to negligible values.

A similar test performed on the Uniform sand exhibited somewhat different results (Figure 4.10). The flow of brine following permeability reduction in the sample again resulted in an increase in permeability. However, the permeability then remained at approximately 41% for 100 pore volumes before dropping to a low point. The introduction of fresh water caused a spike in permeability, however, no long term recovery of permeability was found. Effluent turbidity again shows a high concentration of fines flowing through the sample as the permeability is reduced. A comparison of the permeability in the Uniform sand and the French Drain sand following the tests can be deceiving. The seemingly low value of 40% of the initial Uniform sand permeability is 25 to 37 times higher than the *initial* permeability of the finer French Drain sand.

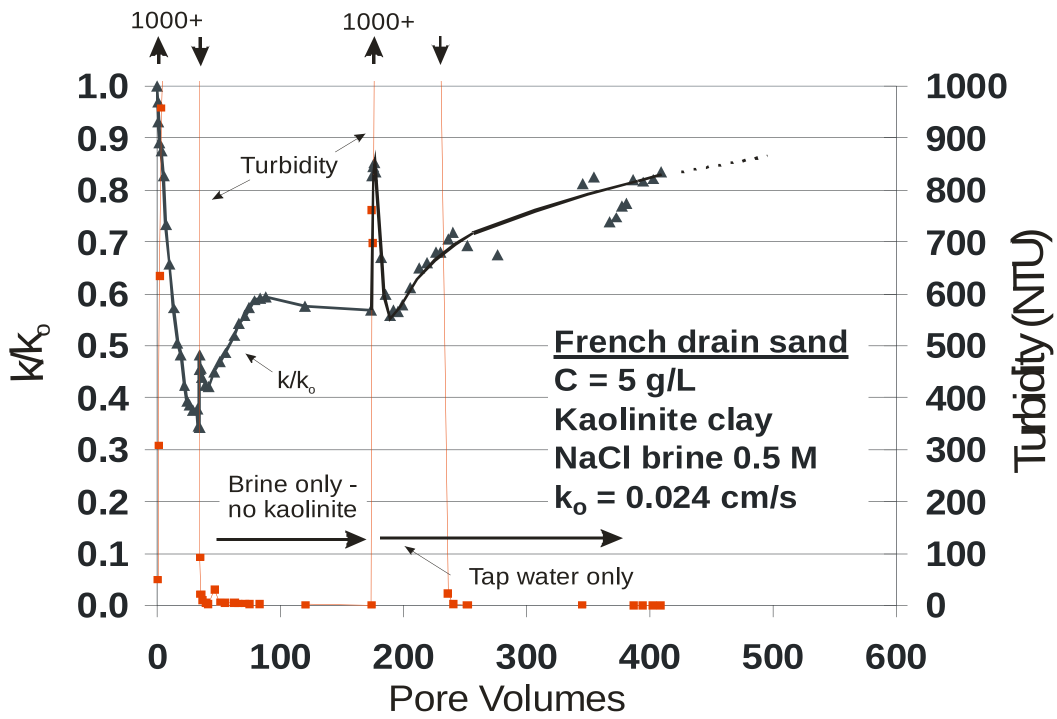

Figure 4.9 – Sand 1 Permeability recovery experimental run, Part 2.

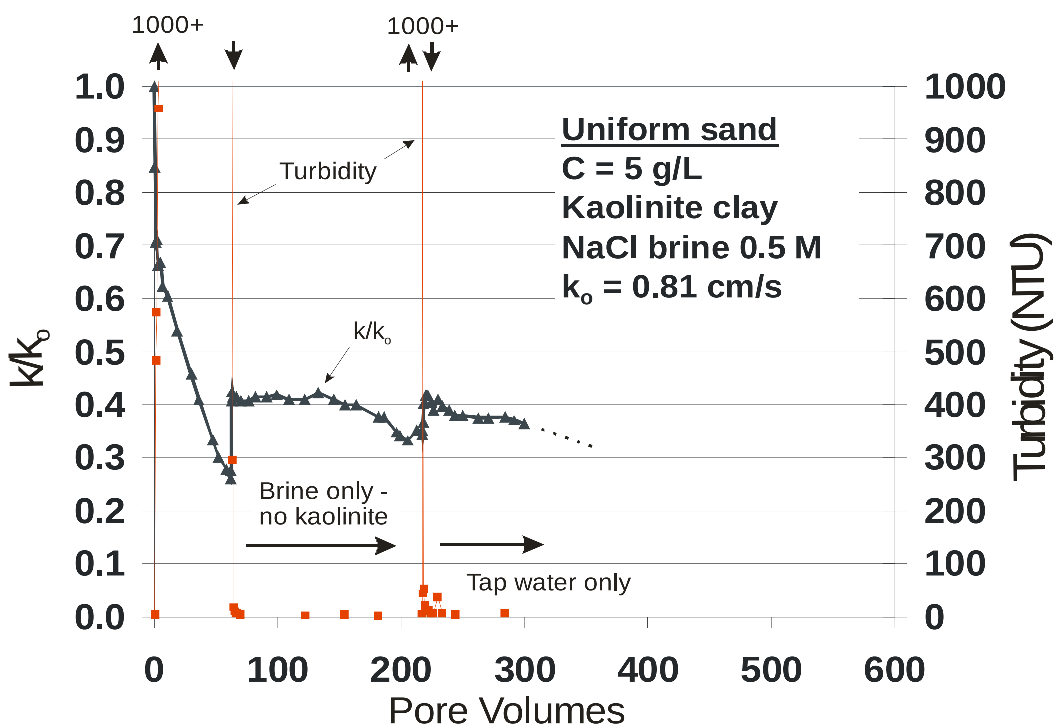

Figure 4.10 – Sand 2 Permeability recovery experimental run.

4.6 Final Procedure Test Results

The main portion of the testing program focused on comparing the rate and magnitude of permeability reduction for the following test variables:

- Type of granular,
- Type of fines,
- Concentration of fines, and
- Ionic strength of the pore water.

An attempt was made to record the fines breakthrough during some of the tests by measuring the mass of fines in the effluent solution at various test intervals. Fines captured within portions of the sample were measured following each test to check the influence on permeability reduction.

4.6.1 Self-Filtration Component of the Granular Tests

The start of each test run involved establishing the permeability of the granular material following self-filtration (k_o). A preliminary permeability was measured following commencement of flow during each test. With some exceptions, the permeability then dropped with the flow of tap or salt water through the sample due to the rearrangement of particles within the sample. Recall that Reddi et al. (2005) found that self-filtration alone could reduce the permeability of a sample by more than 70% after about 200 pore volumes. Additional measurements were taken until the permeability was no longer dropping. This value was the permeability following self-filtration, also used as the initial permeability (k_o) prior to infiltration of fines. Table 4.4 shows the geometric means of these two permeabilities for the tested samples. The calculated Hazen permeability value over-estimates French Drain sand permeabilities and under-estimates Uniform sand permeabilities. Salinity in the pore water generally had the effect of decreasing the measured permeability of the samples. The wide range in measured permeability attests to the variability of the material's particle size distribution, placement in the column, and/or test procedure from sample to sample. The specific (or intrinsic) permeability (with units of length^2) is expressed as:

$$K = \frac{k\mu}{\gamma_w} \tag{4.1}$$

where k is the coefficient of hydraulic conductivity, μ is the viscosity of water, and γ_w the unit weight of water (Reddi, 2003). This equation can be used to compare permeabilities measured under conditions of differing pore fluid characteristics. The viscosity divided by unit weight portion of the equation is 1.047 times higher with the concentration of salt water used, compared with tap water. Thus in theory, measured permeabilities (cm/s) in the salt water tests should be approximately 5% lower than the tap water values.

Table 4.4 – Estimated and average measured permeability values prior to fines infiltration.

	Coefficient of Permeability (cm/s)				
Granular	**Hazen k value**	**Preliminary k**	**k following self-filtration**	**k range**	**Permeant**
French Drain Sand	0.040	0.030	0.026	0.009 to 0.058	Fresh water
		0.022	0.015	0.009 to 0.025	0.5 M NaCl
Uniform Sand	0.36	0.74	0.75	0.50 to 1.09	Fresh water
		0.82	0.67	0.42 to 0.86	0.5 M NaCl
Coarse Gradation	0.49	0.74	0.76	0.54 to 1.09	Fresh water
		0.86	0.40	0.19 to 0.85	0.5 M NaCl

4.6.2 Permeability Reduction – Tap Water Permeant

The tests conducted using tap water as the permeant are shown in Table 4.5. These tests were performed with 5 g/L of fine soil added to the influent tank following stabilization of flow through the sand sample.

Table 4.5 – Constant applied head tests (tap water).

Granular used	Fines used	
	Kaolinite	Battleford Till
French Drain Sand	X	X
Uniform Sand	X	X
Coarse Graded sand	X	X

The test results illustrate that all three sands are prone to clogging, given a constant flow of fines injected under constant head conditions (Figure 4.11). The permeability was reduced by approximately an order of magnitude in each sand; however, more pore volumes of flow were required to reach the same relative reduction in permeability in the coarser sands. Since flow rates are much higher in the two coarser sands, a larger amount of water (and thus more fines) was required to reach the same relative reduction in permeability. Table 4.6 lists the volume of water and the mass of kaolinite used in each test run shown in Figure 4.11.

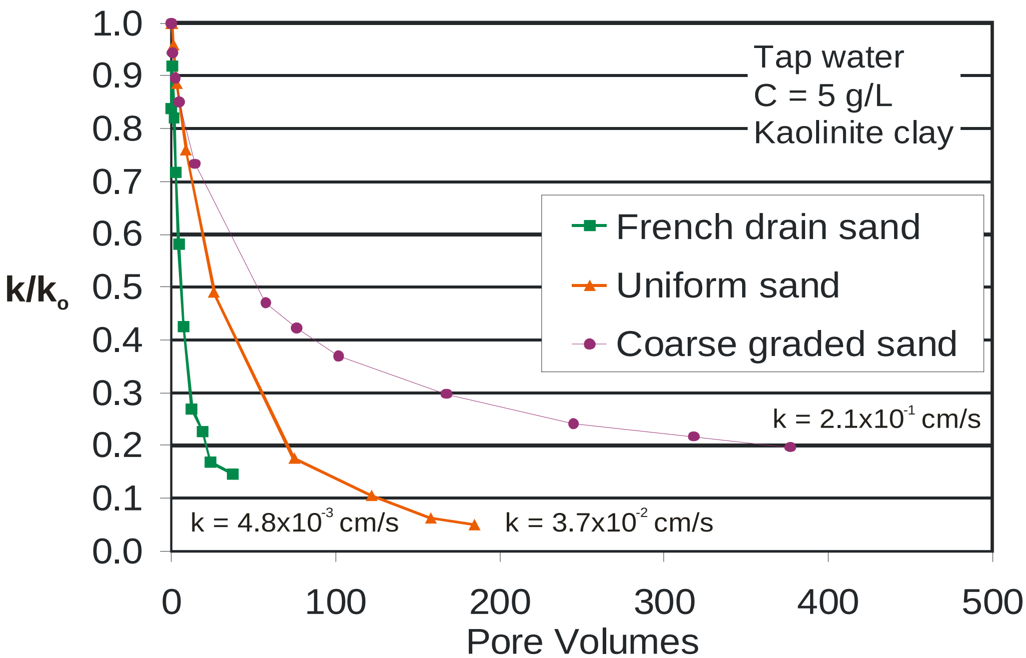

Figure 4.11 – Comparison of permeability reduction (5 g/L kaolinite, tap water).

Table 4.6 – Quantities to reach 20% of initial sample permeability.

	Volume of water used (L)	Mass of fines injected into/through the sample (g)
French Drain sand	16	82
Uniform sand	79	395
Coarse Graded sand	310	1548

Figure 4.12 compares permeability reduction in the three sands through the use of Battleford Till fines.

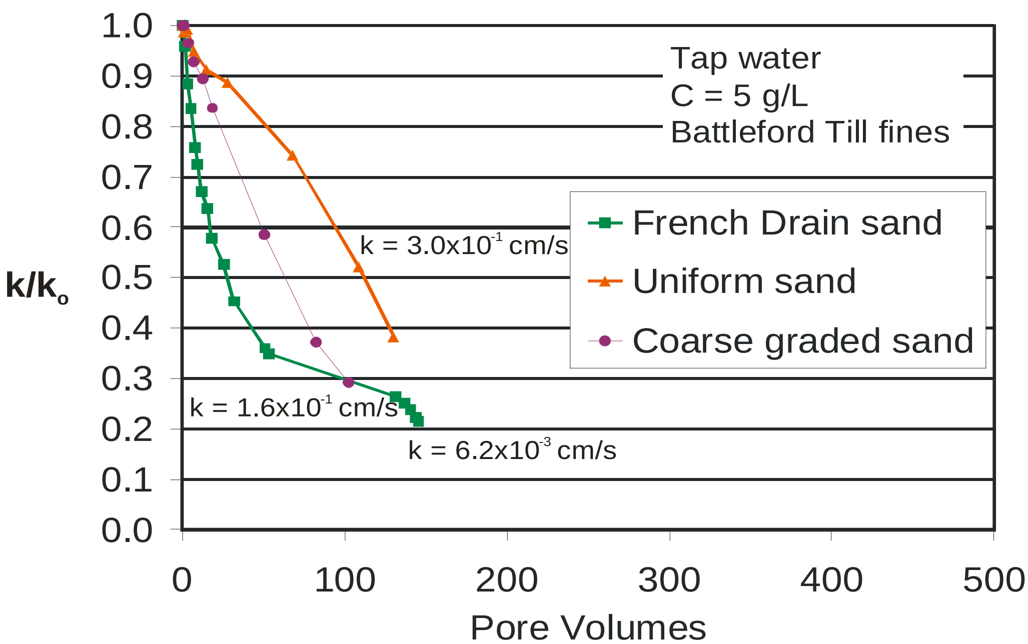

Figure 4.12 - Comparison of permeability reduction (5 g/L Battleford Till fines, tap water).

4.6.3 Permeability Reduction – Salt Water Permeant.

Tests were conducted with salt water as the permeant in order to quantify changes in permeability reduction and to relate the results to expected field conditions. Table 4.7 displays the materials used for the 5 g/L concentration tests.

Table 4.7 – Constant applied head tests (salt water and 5 g/L fines).

Granular used	Fines used (5 g/L)		
	Kaolinite	Battleford Till	Regina Clay
French Drain Sand	X*	X	X
Uniform Sand	X*	X	
Coarse Graded sand	X*	X	

*Additional tests run with tap water flow prior to addition of fines.

Figures 4.13 and 4.14 show how kaolinite and Battleford Till fines reduced the permeability of various granular soils under salt water conditions. The literature indicates that increasing ionic strength makes deposition conditions favourable. The addition of salt to the permeant water did not have the expected effect of increasing the rate of permeability reduction. The most likely reason for the negligible effect on permeability is the small fraction of clay sized particles present in the influent. As explained earlier, all three types of fines used in the testing had low clay content (approximately 10% in the kaolinite and 5% in the Battleford Till and Regina Clay).

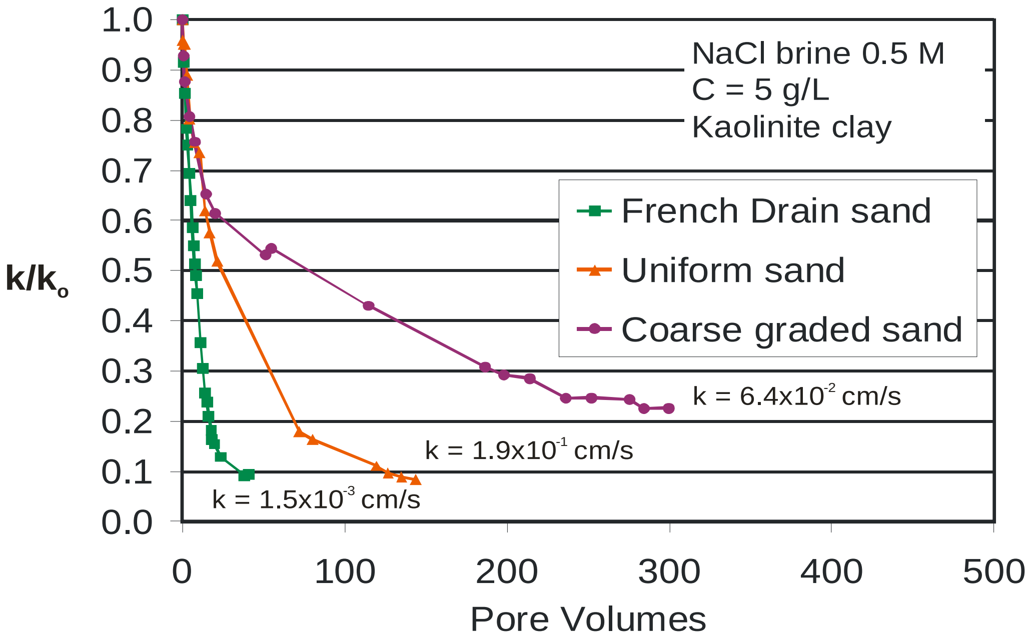

Figure 4.13 – Comparison of permeability reduction (5 g/L kaolinite, salt water).

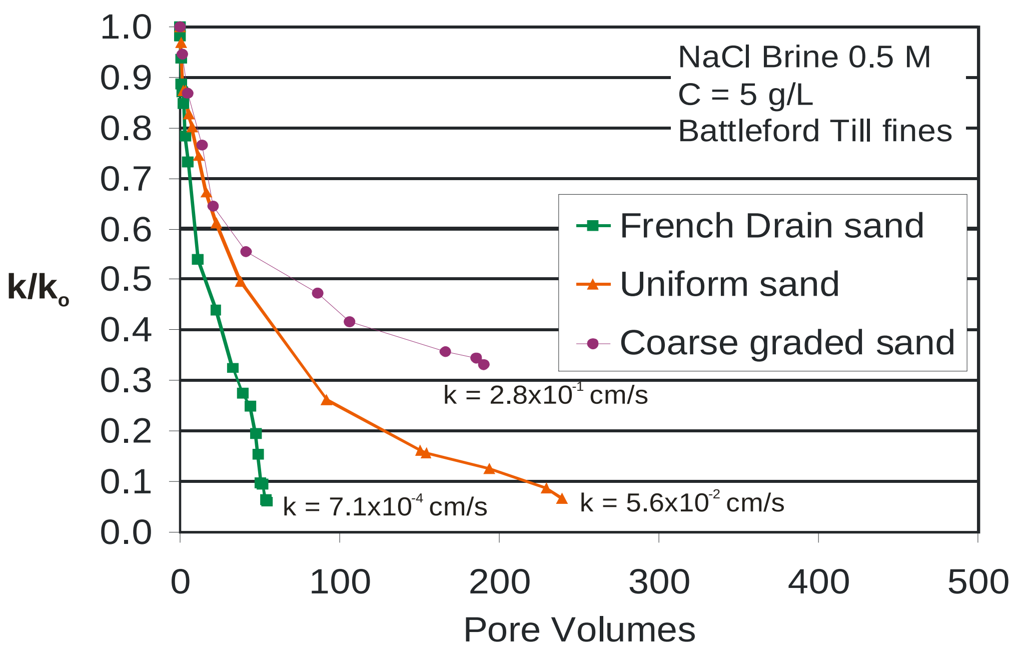

Figure 4.14 – Comparison of permeability reduction (5 g/L Battleford Till fines, salt water).

The concentration of 5 g/L is a relatively heavy load which would likely not be seen under low gradient field conditions. Table 4.8 displays which tests were performed with 1 g/L fines.

Table 4.8 – Constant applied head tests (salt water and 1 g/L fines).

Granular used	Fines used (1 g/L)		
	Kaolinite	Battleford Till	Regina Clay
French Drain Sand	X	X	X
Uniform Sand	X	X	
Coarse Graded sand	X	X	

Lowering the fines concentration to 1 g/L slows the time rate of permeability reduction, as expected, in all three drain materials. The kaolinite and Battleford Till fines curves are shown in Figure 4.15 and Figure 4.16, respectively. The overall percent reduction in the permeability of the Coarse Graded sand is not as severe with the lower fines concentration. In the case with Battleford Till fines, the permeability of the Coarse Graded sand was lowered by only 28% (Figure 4.16). It appears that the coarse material could handle the small load of fines without losing a significant amount of permeability. Continued self-filtration of the filter sand during the test is a possible explanation for the variation in permeability in the Coarse Graded sand, particularly in the test using Battleford Till fines.

The permeability of the French Drain sand seemed to decrease at roughly the same rate as the Uniform sand in both cases. This result differs from the tests run using 5 g/L fines, where the French Drain sand permeability dropped faster than the Uniform sand permeability. This may indicate that a graded sand/gravel mix may be better at retaining permeability than a filter of Uniform size when exposed to a constant low concentration of fines.

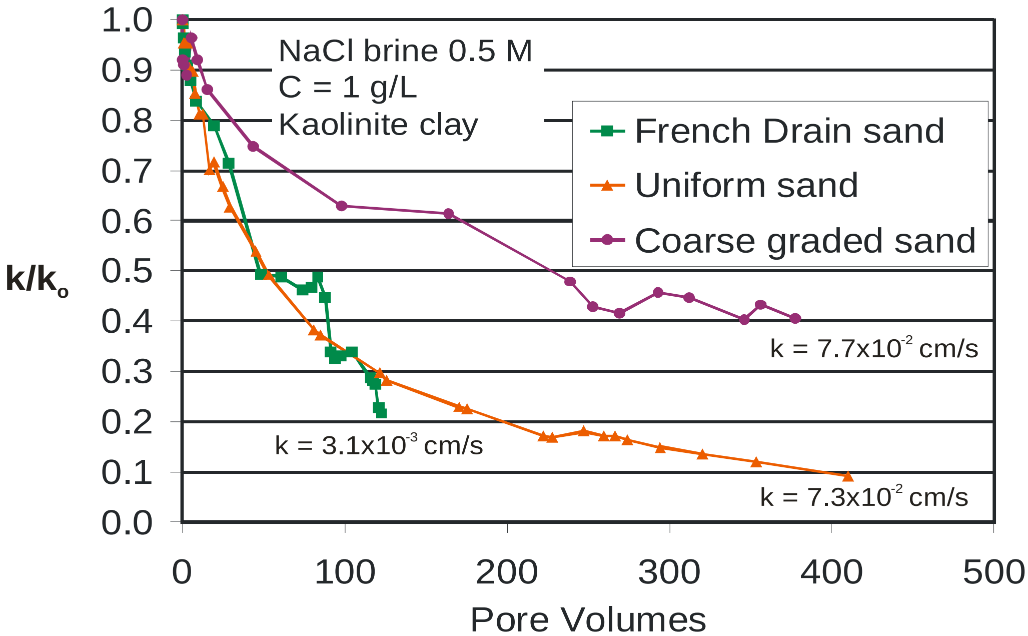

Figure 4.15 – Comparison of permeability reduction (1 g/L kaolinite, salt water).

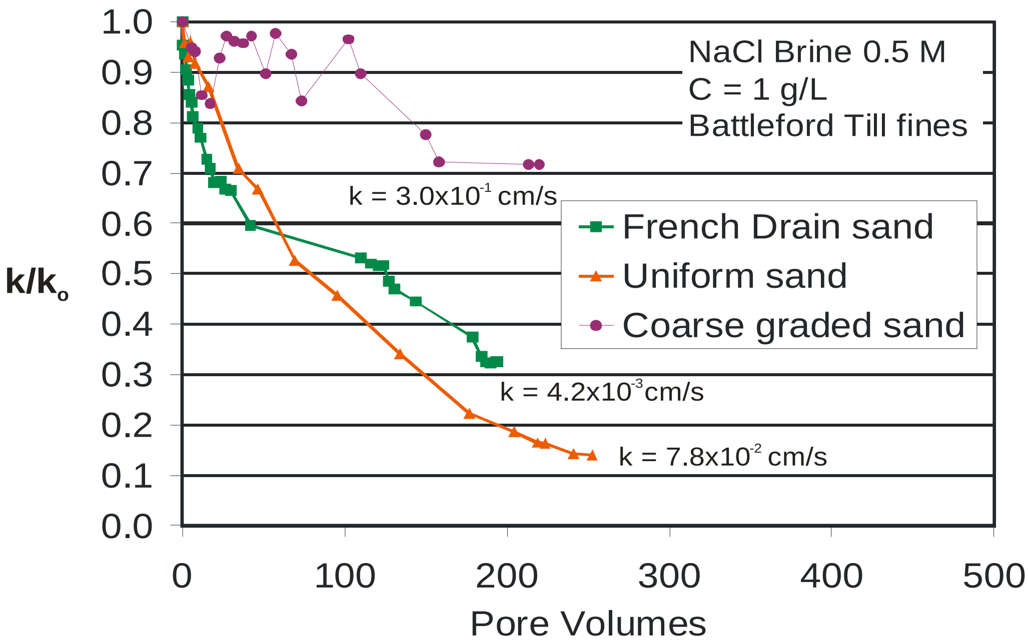

Figure 4.16 – Comparison of permeability reduction (1 g/L Battleford Till fines, salt water).

4.6.4 Comparison of Fines Capture Within the Column Tests

A third concentration of fines (2.5 g/L) was used in tests on French Drain sand and Coarse Graded sand (Table 4.9).

Table 4.9 – Constant applied head tests (salt water and 2.5 g/L fines).

Filter Sand	Fines
	Kaolinite
French Drain sand	X
Uniform sand	
Coarse Graded sand	X

Following the majority of final procedure tests, the samples were split into equal portions (6 portions in most cases, 3 portions in others). The fines content of each portion was then measured by wash sieve testing. The results are shown in Table 4.10. The table is organized into four main categories of tests: tap water influent with 5 g/L fines, and 0.5 M NaCl influent with 5 g/L, 2.5 g/L, and 1 g/L fines, respectively. Each sand plus fines combination represents one test run. The effluent end of each sample was the top of the column while the influent end was the bottom of the column.

Prior to testing, the French Drain sand contained approximately 3% fines (approximately 125 g of the roughly 4400 g column sample), while the Uniform sand and the Coarse Graded sand contained negligible amounts of fines.

Table 4.10 shows that each of the three sands retained similar volumes of fines during the testing, regardless of:

- Fines concentration in the influent;

- Total mass of fines injected; or
- Tap water or salt water as the influent.

Arrows are included on the table for the tests that showed a decreasing concentration of fines from the influent end to the effluent end. The solid arrows indicate a strong correlation between fines content and location within the column. The dashed arrows indicate a weak or unclear correlation. The tests that were split into 3 or 4 portions all show dashed arrows.

It was expected that fines would become trapped within the sand columns during the tests. One would expect that fines would begin to be trapped at the onset of the flow of fines through each sample. In theory, fines either become trapped in pore throats or deposit on pore walls if flow conditions allow. Once fines become deposited, the pore size distribution of the sample is altered, and the opening size of the filter material (defined by D_{15} / 9) becomes smaller. Thus, only successively smaller particles can pass through the filter material as flow continues through the sample.

The measured fines concentrations within the samples were commonly between 2 and 5%. This seems to indicate that there is a maximum fines concentration load when considering the three filter sands tested. Once this concentration was reached, any further fines loading apparently flowed through the sand. However, this condition was reached much sooner in the case of the French Drain sand. The mass of fines injected in the French Drain sand tests was, in general, much lower than the mass of fines injected in the two coarser sands.

There were likely a number of relatively large pores in each filter sand that allowed all fine material through. Some of these pores likely became plugged with a “bridge” of fines, due to the continuous high concentration attempting to pass through. The main difference in the case of the French Drain sand was that there were fewer large pores. As more pores became plugged, there were fewer routes for the flow to take, resulting in a drop in permeability. Jumps in permeability could be explained by the fines “bridges” being pushed through the pore.

The results will be discussed further in the next sections.

Table 4.10 – Percent fines measured within sample sections.

Solution, concentration	Sample	French drain sand Kaolinite	French drain sand Battleford Till	French drain sand Regina clay	Uniform sand Kaolinite	Uniform sand Battleford Till	Coarse graded sand Kaolinite	Coarse graded sand Battleford Till
Tap water	Effluent end	3.6%	3.7%		3.3%	1.2%	2.8%	2.9%
5 g/L fines in influent		3.4%	3.4%		3.4%	2.2%	3.1%	2.7%
	Centre	4.0%	3.4%		3.5%	3.0%	3.4%	1.6%
	Centre	4.3%	3.5%		3.9%	3.7%	3.7%	1.4%
		4.3%	3.7%		3.6%	3.3%	3.2%	1.8%
	Influent end	4.5%	5.3%		4.0%	10.3%	4.2%	3.1%
Percent fines measured in entire column		4.1%	3.8%		3.6%	4.2%	3.4%	3.3%
Post-test total mass of fines (g)		155	151		125	149	130	128
Mass of fines injected (g)		185	519		978	689	1548	543
0.5 M NaCl influent	Effluent end	3.5%	4.5%	2.2%	1.0%	2.3%	3.3%	3.9%
5 g/L fines in influent		3.3%					3.5%	2.8%
	Centre	3.9%	5.1%	2.9%	1.2%	2.3%	2.5%	2.9%
	Centre	4.8%		3.5%			4.1%	2.9%
		4.7%					4.6%	2.6%
	Influent end	5.2%	5.3%	4.3%	2.2%	6.6%	4.8%	1.5%
Percent fines measured in entire column		4.2%	5.0%	2.9%	1.5%	4.1%	3.8%	2.8%
Post-test total mass of fines (g)		168	195	115	51	147	147	102
Mass of fines injected (g)		141	187	43	844	1267	1230	780
0.5 M NaCl influent	Effluent end	4.8%					2.7%	
2.5 g/L fines in influent		4.3%					1.7%	
	Centre	4.2%					2.3%	
	Centre	3.6%					1.5%	
		3.0%					2.0%	
	Influent end	3.3%					2.1%	
Percent fines measured in entire column		3.8%					2.0%	
Post-test total mass of fines (g)		150					150	
Mass of fines injected (g)		84					662	
0.5 M NaCl influent	Effluent end	3.1%	4.1%	3.4%		4.1%	2.5%	2.9%
1 g/L fines in influent		2.9%	3.7%	3.0%		3.6%	3.0%	2.7%
	Centre	3.3%	3.8%	3.3%		4.4%	3.4%	1.6%
	Centre	3.3%	3.5%	3.9%		4.7%	2.7%	1.4%
		4.0%	3.3%	4.0%		5.2%	3.1%	1.8%
	Influent end	5.3%	3.0%	4.7%		7.8%	3.2%	3.1%
Percent fines measured in entire column		3.7%	3.6%	3.7%		5.0%	3.0%	2.2%
Post-test total mass of fines (g)		146	139	140		179	114	84
Mass of fines injected (g)		84	134	67		277	310	181

4.6.5 Comparison of Permeability Reduction Due to Mass Loading

The test results were presented earlier comparing the permeability reduction in the three sands due to inflow one of the fines. In this section, the permeability reduction in each sand will be studied individually. The varying concentrations of fines injected and the pore volumes of fines injected will be looked at respectively. The latter method of presenting the data considers the rate that the mass of fines was delivered into each sample. The pore volume of fines injected is presented as the mass of fines injected divided by the mass of fines retained. This may help to determine whether the rate of permeability reduction is controlled by the mass of fines injected into a sample rather than concentration of fines in the influent.

The French Drain sand is presented in Figure 4.17 with the three concentrations of kaolinite used during the tests. Decreasing the mass of fines entering the drain over a period of time lessens the impact on drain permeability. The test using 1 g/L kaolinite fines took 3 to 4 times more pore volumes of flow than the tests using 2.5 g/L and 5 g/L to reach 20% of its initial permeability. Further to this, the permeability did not drop lower than 20% of the original permeability prior to stopping the test (when two consecutive measurements showed steady permeability). The data from the same three tests is presented in Figure 4.18 in terms of pore volumes of fines injected. The abscissa is a ratio of the mass of fines injected divided by the mass of fines retained in the column. One pore volume of fines is the mass retained in the column. Table 4.10 indicates that an average 155 g of kaolinite remained in each sample of French Drain sand following the tests. Since there were roughly 125 g of fines within the French Drain sand prior to the tests, one pore volume of fines was taken to be 30 g. The sand shows a 50% reduction in permeability after 0.7

to 1.1 pore volumes of kaolinite fines. The test that used 1 g/L kaolinite fines required more pore volumes of fines to reach 20% of its original permeability.

Figure 4.19 compares the French Drain sand test runs with Battleford Till fines. Again, it took more pore volumes of flow to lower the permeability with a lower concentration of fines (1 g/L) when compared with a higher concentration of fines (5 g/L). When the two test runs are compared in terms of pore volumes of fines through each sample (Figure 4.20), however, the loss in permeability is shown to depend only on the mass of fines entering the column.

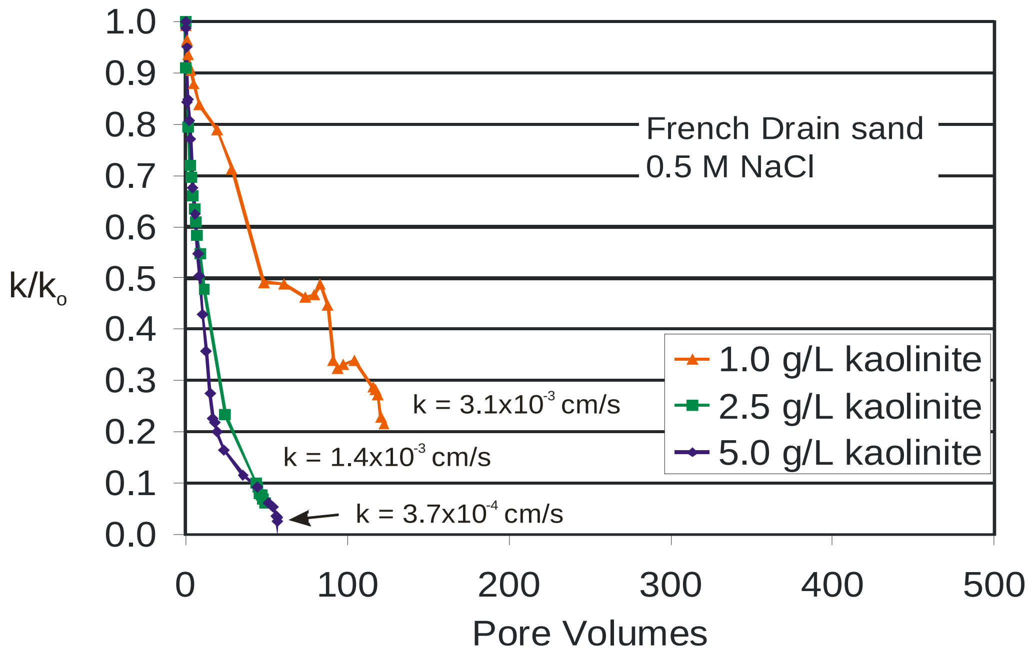

Figure 4.17 – Permeability loss in French Drain sand due to water pore volumes with kaolinite).

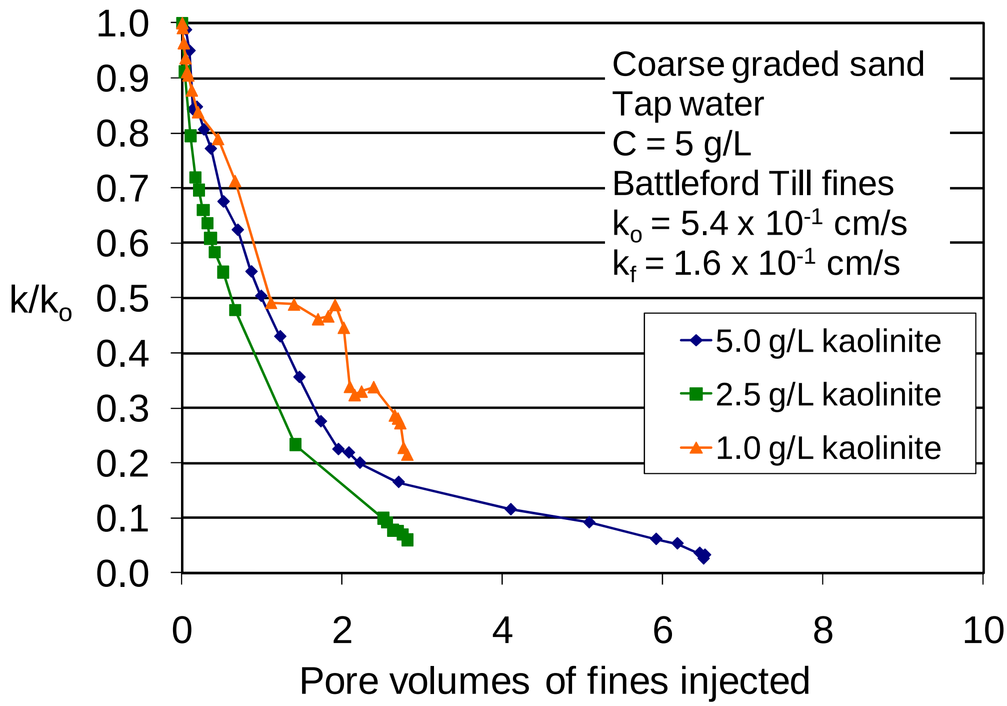

Figure 4.18 - Permeability loss in French Drain sand due to kaolinite fines pore volumes.

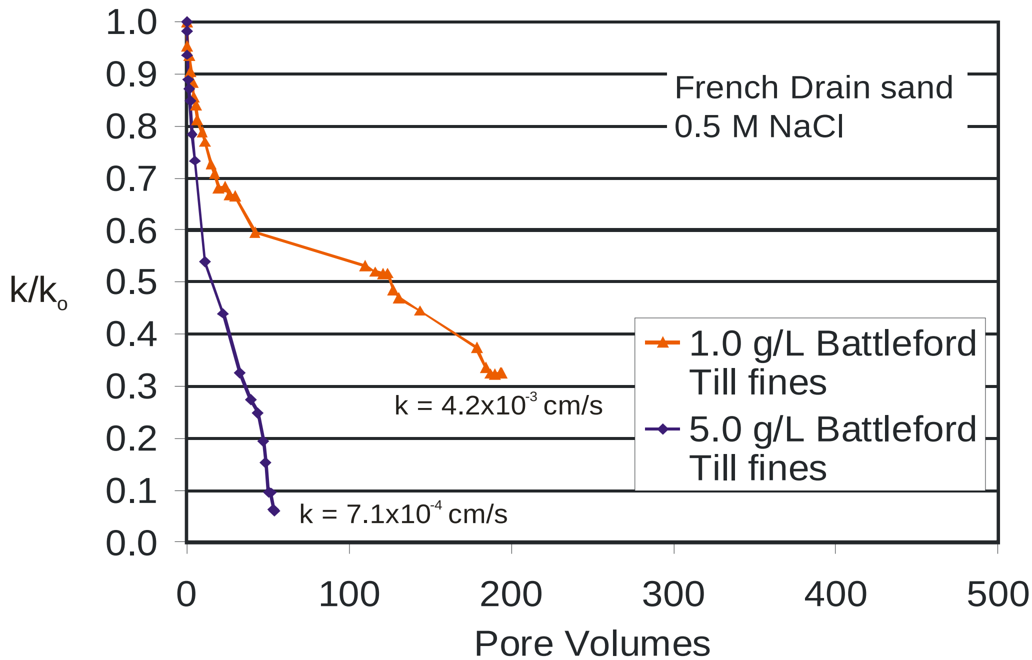

Figure 4.19 – Permeability loss in French Drain sand due to water pore volumes with Battleford Till fines).

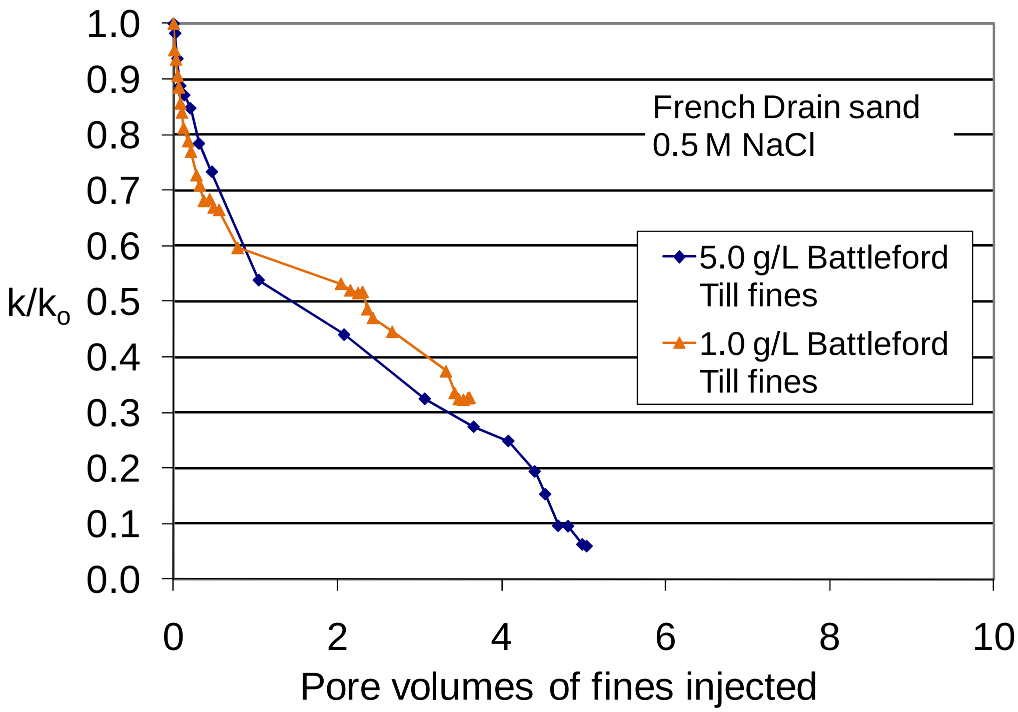

Figure 4.20 – Permeability loss in French Drain sand due to Battleford Till fines pore volumes.

The Uniform sand test results are shown in the next four figures and compare the reduction in permeability caused by kaolinite and Battleford Till fines (Figure 4.21 to Figure 4.24). The difference in fines concentration appeared to have little effect on the Uniform sand. In the case of the Uniform sand infiltrated with Battleford Till fines, the permeability was reduced to nearly the same extent in the same number of pore volumes of flow (Figure 4.23). The lower concentration of fines actually had a larger impact on permeability reduction when considering the rate at which the fines entered the columns (Figure 4.22 and 4.24). In the case of the Uniform sand, one pore volume of fines was considered to be 150 g for both kaolinite and Battleford Till fines.

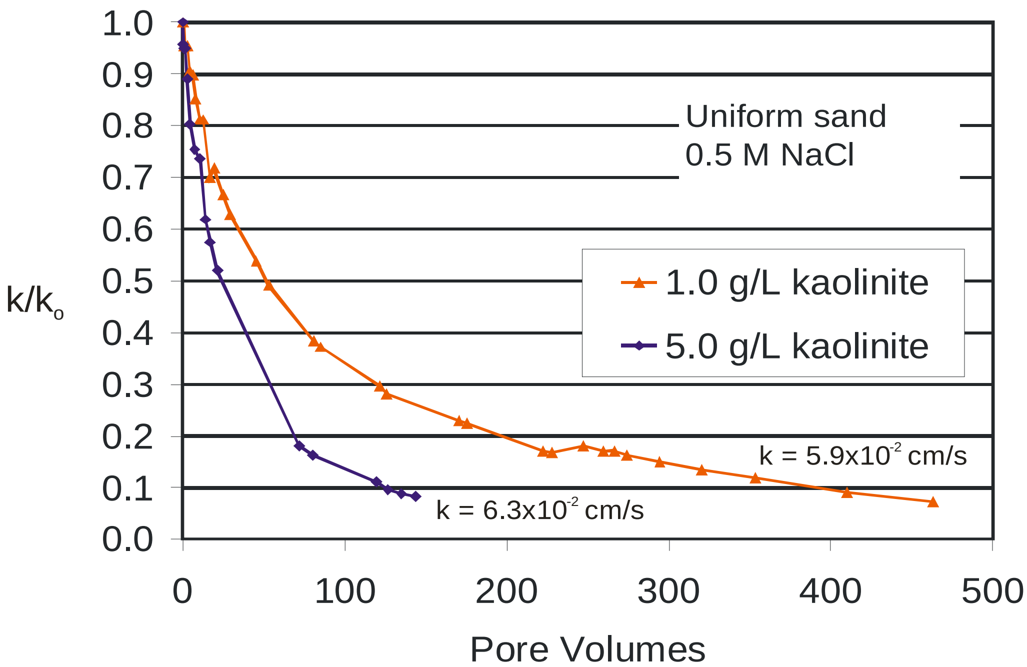

Figure 4.21 – Permeability loss in Uniform sand due to water pore volumes with kaolinite.

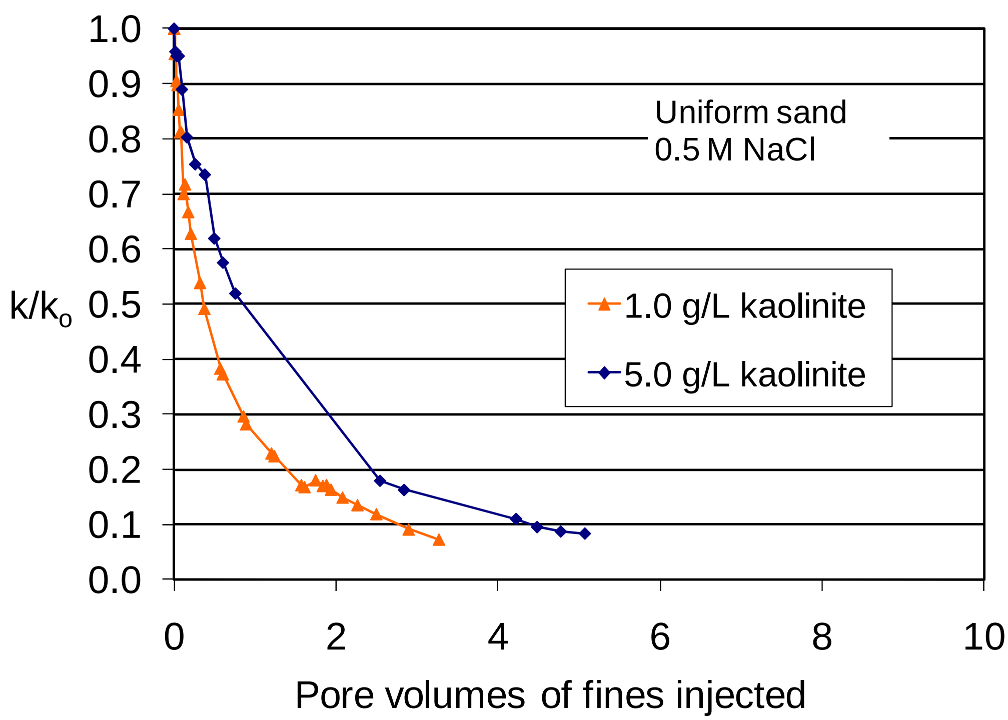

Figure 4.22 – Permeability loss in Uniform sand due to kaolinite fines pore volumes.

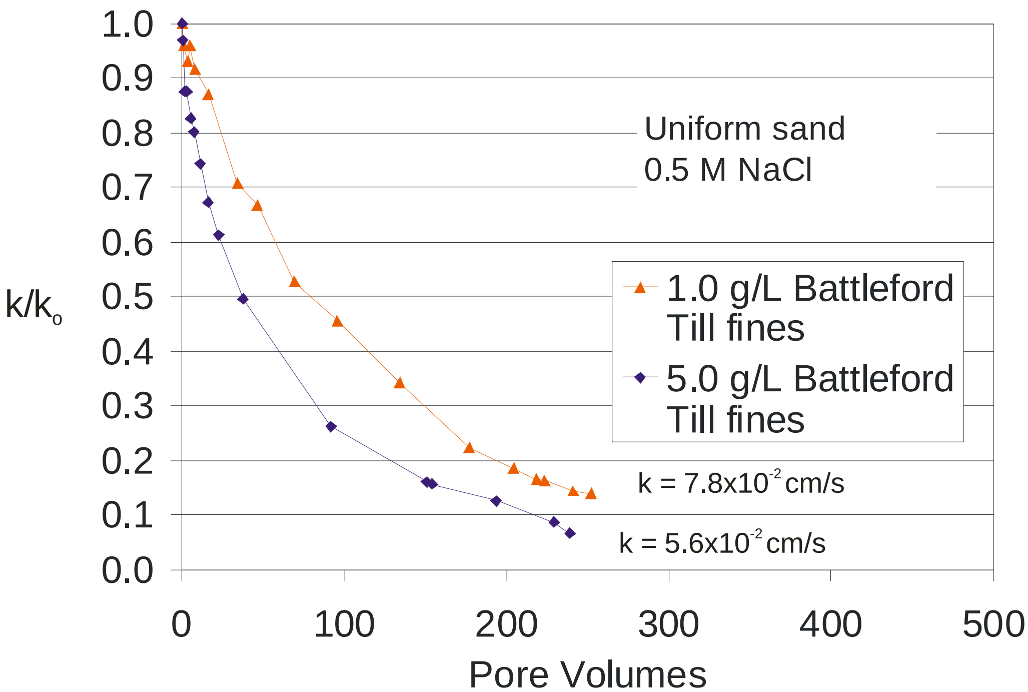

Figure 4.23 – Permeability loss in Uniform sand due to water pore volumes with Battleford Till fines).

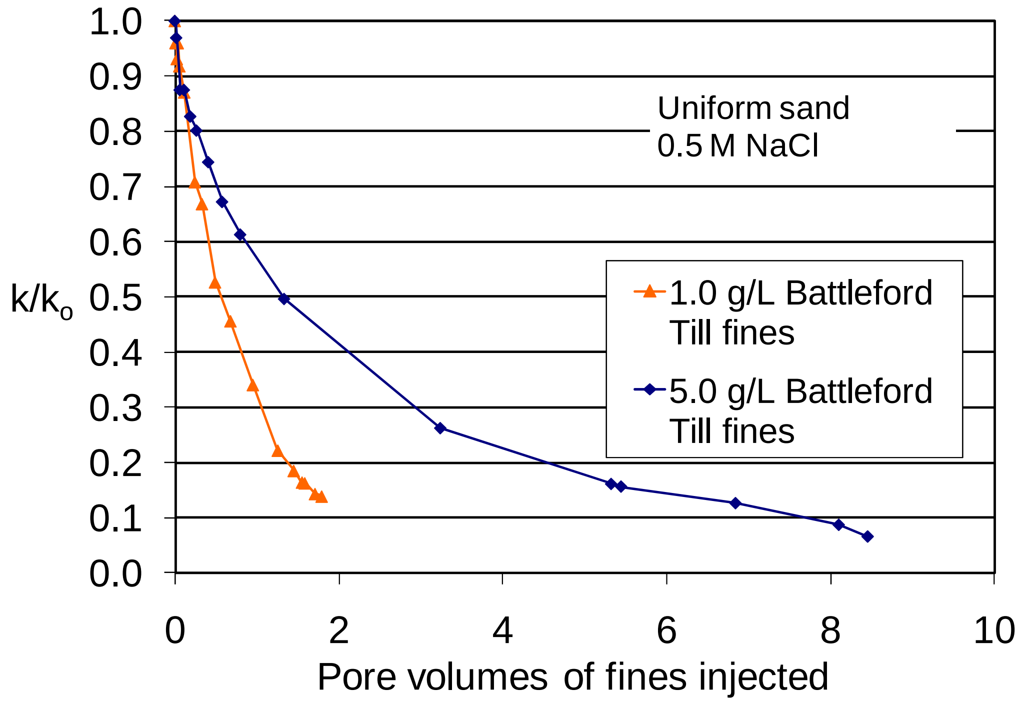

Figure 4.24 – Permeability loss in Uniform sand due to Battleford Till fines pore volumes.

Finally, the Coarse Graded sand test results are shown in Figure 4.25 through Figure 4.28. The Coarse Graded sand results are similar to the French Drain sand results, in that both showed relatively large differences in the rate and extent of permeability reduction when comparing the 5 g/L fines concentration tests with the 1 g/L tests in terms of pore volumes of flow. Presenting the results in terms of pore volumes of fines (Figure 4.26 and Figure 4.28) shows that permeability reduction is ultimately influenced by the total mass of fines injected. One pore volume of fines was 135 g of kaolinite and 105 g of Battleford Till fines.

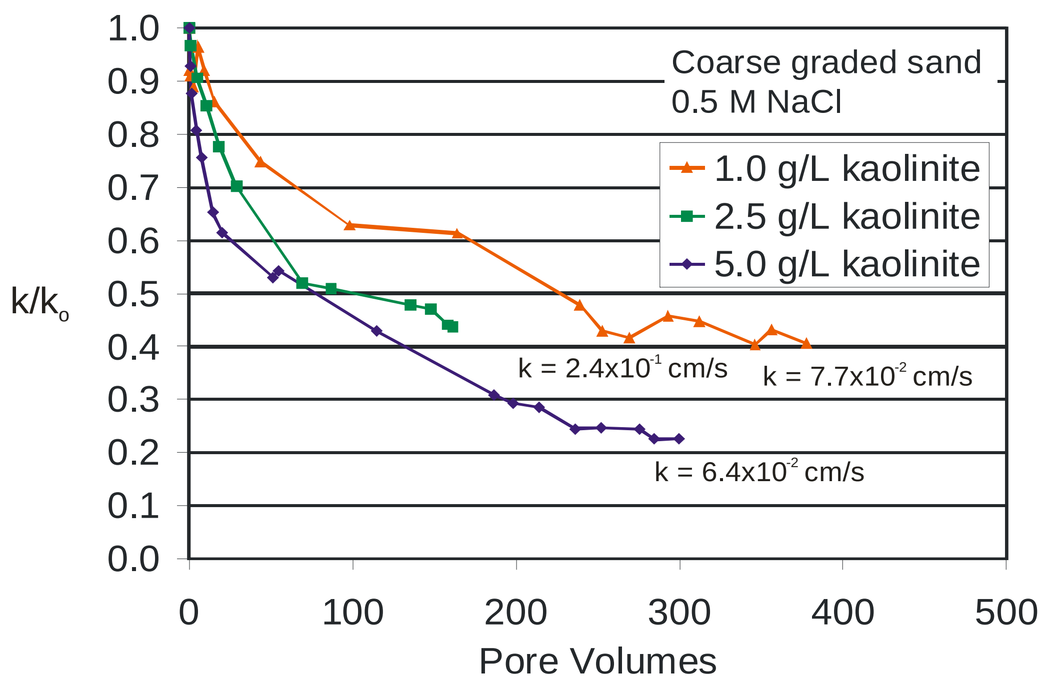

Figure 4.25 – Permeability loss in Coarse Graded sand due to water pore volumes with kaolinite fines).

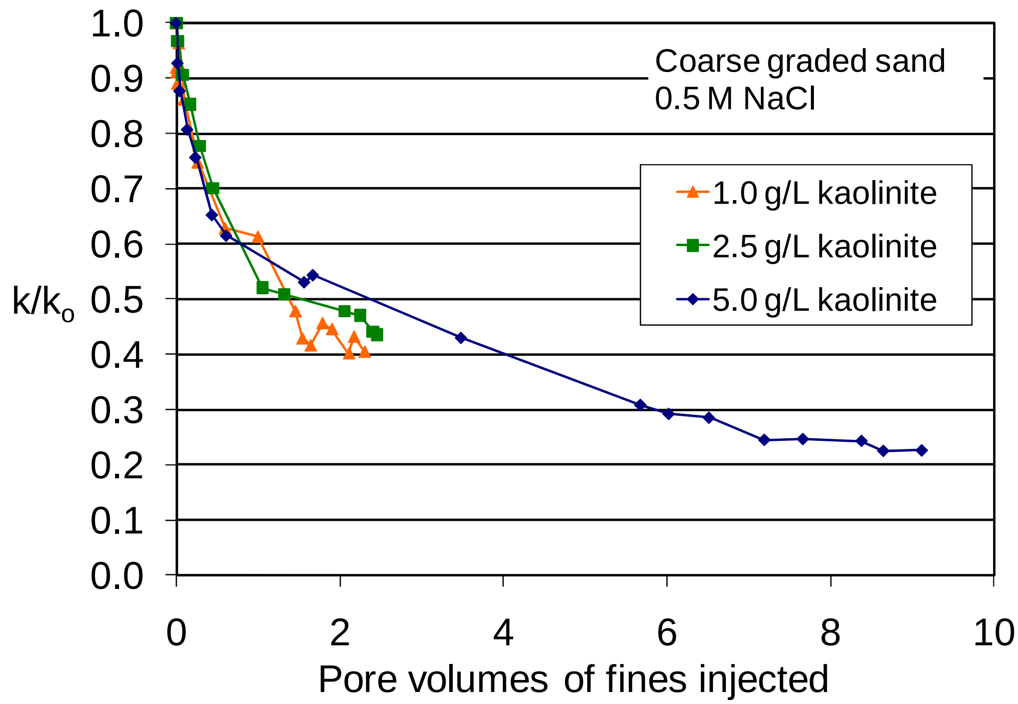

Figure 4.26 – Permeability loss in Coarse Graded sand due to kaolinite fines pore volumes.

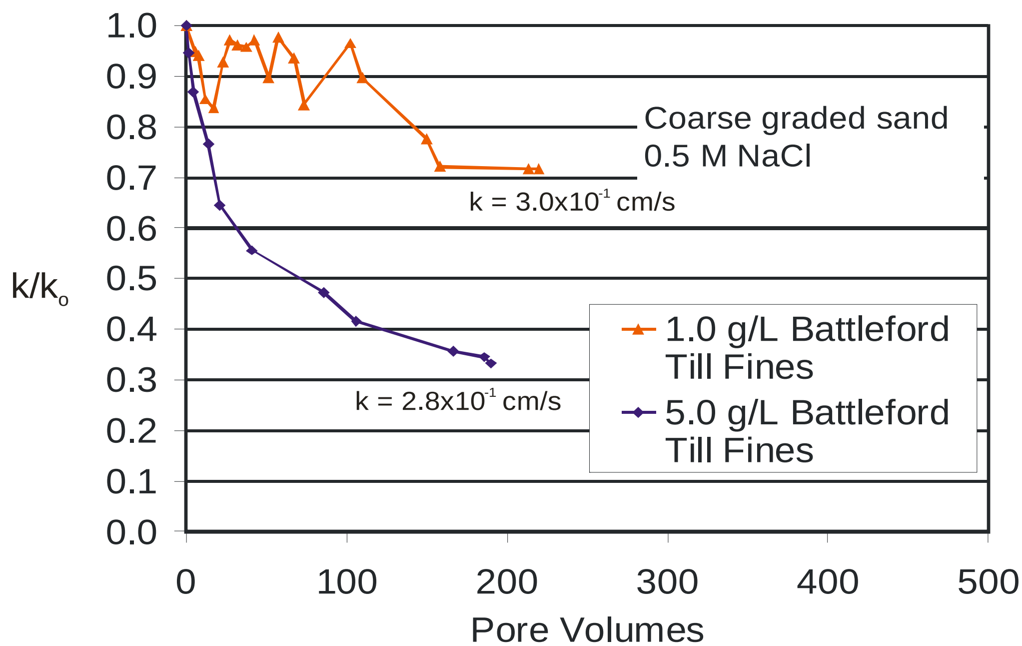

Figure 4.27 – Permeability loss in Coarse Graded sand due to water pore volumes with Battleford Till fines).

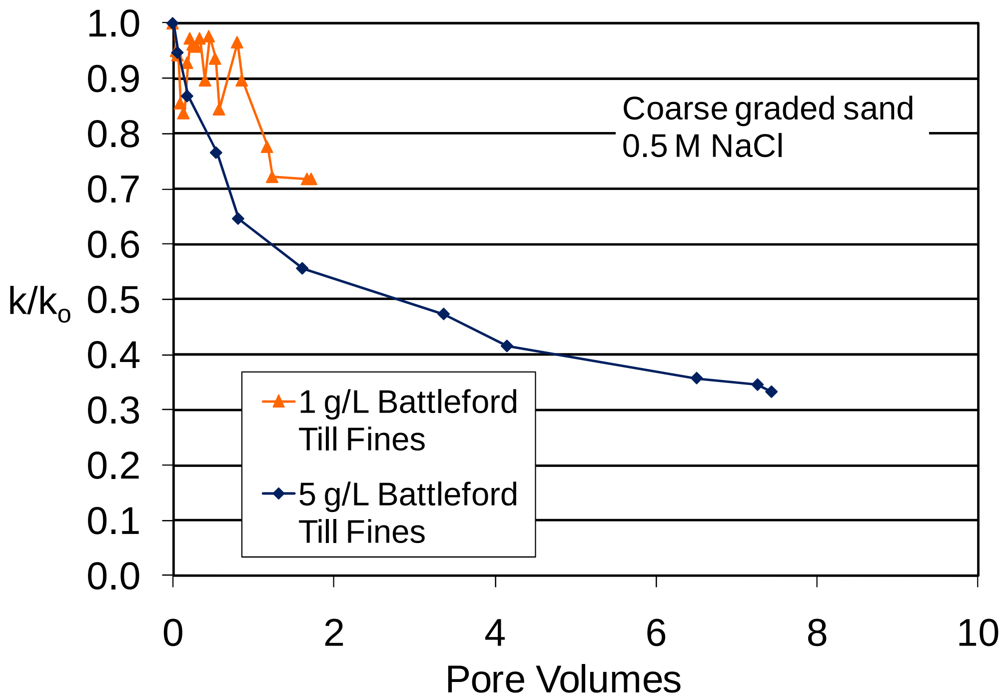

Figure 4.28 – Permeability loss in Coarse Graded sand due to Battleford Till fines pore volumes.

The Uniform sand did not perform as well as the graded sands under low concentration fines flow. Since low concentrations of fines negatively affect the Uniform sand to nearly the same extent as high concentrations, this may indicate that a graded sand provides better "protection" against clogging than a Uniform sand. This is an unanticipated result from the testing.

4.6.6 Fines Capture and Breakthrough – Comparison of Test Results

This section presents further discussion on fines capture, effect of salinity, and maximum fines "loads" within the samples tested. Breakthrough curves are presented in this section. These graphs present measured fines concentrations at a particular moment in time during a test run. Concentrations are plotted against pore volumes of flow.

Test runs are presented in this section with relative permeability reduction (k/k_o) vs. pore volumes of flow. In all cases, the turbidity of the effluent was measured by taking grab samples throughout each test. For simplicity, the turbidity is not shown on the graphs. The effluent turbidity climbed quickly at the start of each test and exceeded 1000 NTU within 10 pore volumes of flow.

An observation of note was made regarding the effect of salinity in the pore water. In some cases, brine lessened the filtration component within the drain as pores became clogged. This is best illustrated in Figure 4.29 and Figure 4.30. With tap water used as the permeant, the permeability at the influent end of the column dropped significantly more than at the effluent end of the column (Figure 4.29). With salt water used as the permeant, however, the permeability dropped at nearly the same rate at both the influent and effluent ends of the column (Figure 4.30). The only difference between the two tests was the salinity of the pore water. The results of the wash sieve tests (Section 4.6.4) show that nearly the same mass of fine particles was deposited within the drain material during the tests (130 g for the tap water test and 147 g for salt water test). Also, the material at the entrance to the column (1/6th of the height of the column) showed the highest percentage of fines trapped in both cases (4.2% and 4.8% fines by mass, respectively). There is also little difference in the distribution of fines throughout the column in each test. The remaining fines contents (from the other five post-test wash sieves) range from 2.8% to 3.7% in the tap water test and 2.5% to 4.6% in the salt water test.

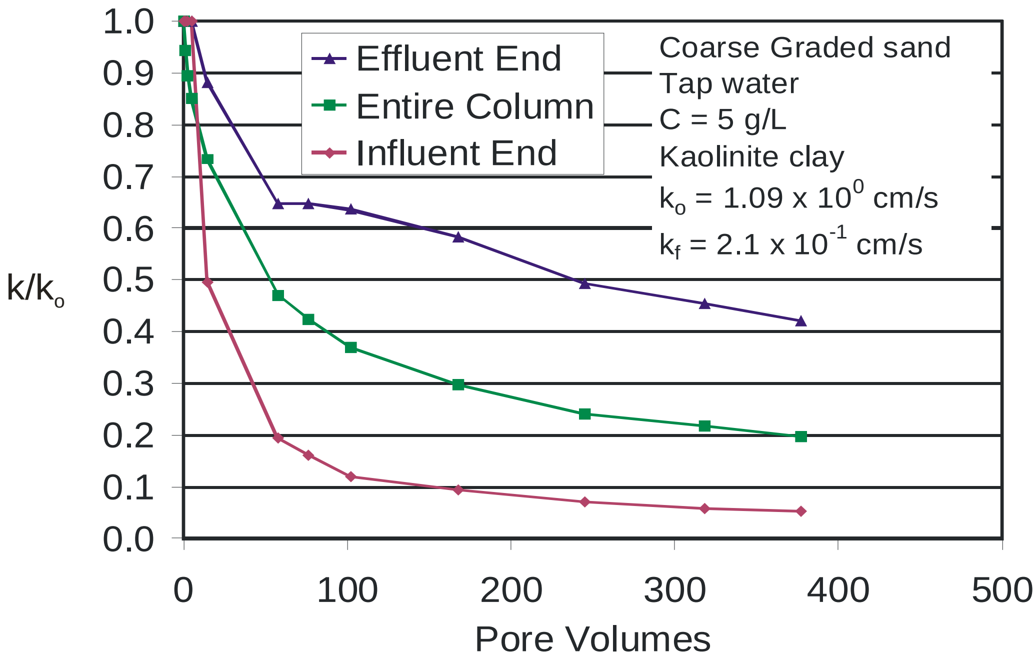

Figure 4.29 – Permeability reduction over portions of the sample (tap water).

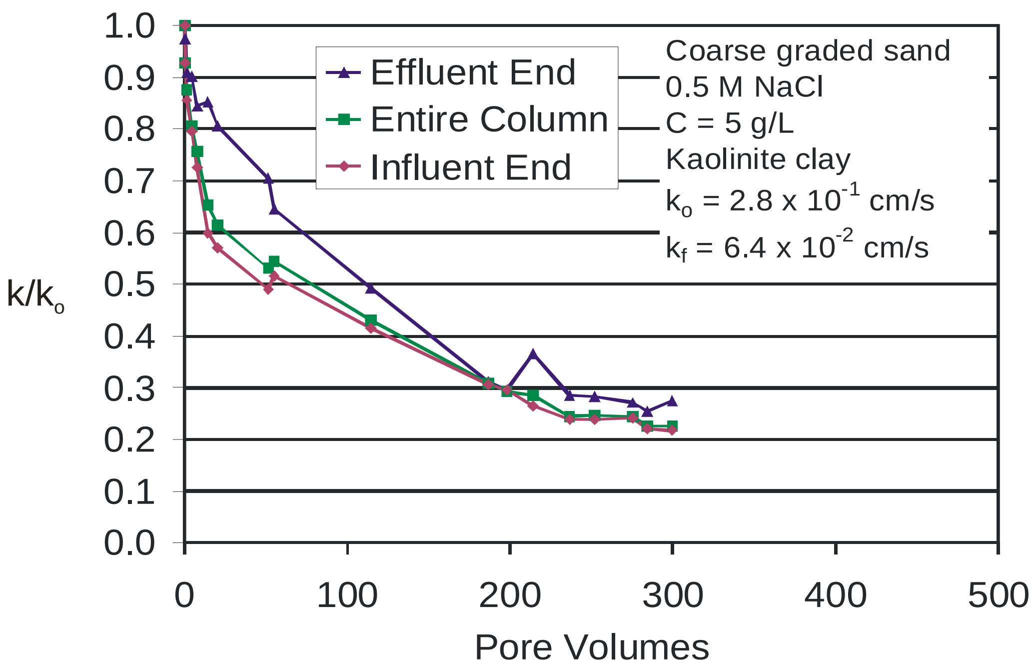

Figure 4.30 – Permeability reduction over portions of the sample (salt water).

A lower concentration of fines (1 g/L) injected into the same drain material with salt water as the permeant returns similar results (Figure 4.31). The permeability appears to drop almost evenly across the column. The total mass of fines found within the drain material following the test was 114 g. The distribution of fines was essentially balanced throughout the column and ranged from 2.5% to 3.4%. The highest proportion of fines was not found at the influent end of the column. It is apparent from these results (and the illustrated results) that the drain was not overwhelmed by the relatively small concentration of fines in the influent. The fines were able to move through the pores more readily under the lower concentration. There were more ups and downs in the permeability of the Coarse Graded sand during this test. This may be a result of continued self-filtration throughout the test. The particle concentration in the influent may have been low enough that particle rearrangement was able to increase permeability momentarily during the test.

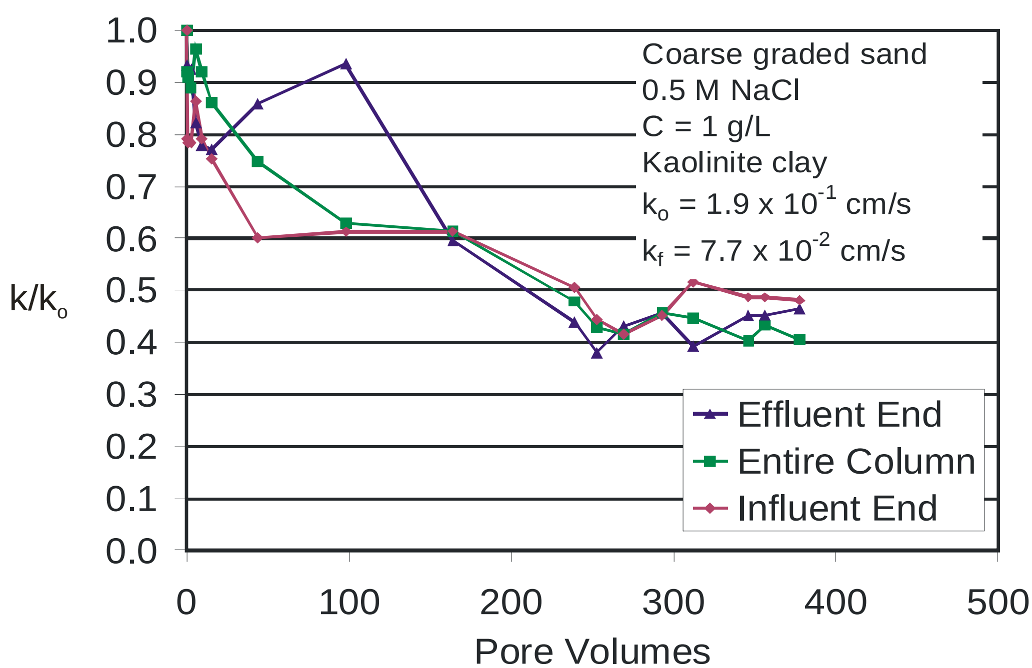

Figure 4.31 – Permeability reduction over portions of the sample (salt water).

It is apparent that there is a certain capacity of fines that the drain material can handle at which time the permeability of the sample does not decrease further to any great extent. The masses of fines measured following the tests in the Coarse Graded sand fell within the relatively small range of 114 g to 147 g. A breakthrough curve (Figure 4.32) based on the test shown in Figure 4.29 shows that "equilibrium" was reached at roughly 100 pore volumes of flow in this test. This means that the effluent concentration of fines equaled the influent concentration of fines at this point. The permeability of the sample at equilibrium was 37% of the original permeability. It further decreased to 20% after nearly 400 pore volumes of flow. The results seem to indicate that once equilibrium is reached, pathways exist within the granular for nearly all the influent fines to migrate through the sample. The data in Figure 4.32 can be used to estimate the mass of kaolinite within the sample during the test. At the point of breakthrough, the mass of kaolinite within the sample can be estimated by the area on the graph between the horizontal line representing the inflow rate (5 g/L) and the curve connecting the measured outflow kaolinite concentrations (from 0 to 100 pore volumes). This amounts to approximately 100 g of kaolinite within the sample. During the next phase of the test, the effluent concentration measured higher than the inflow rate of 5 g/L, so mass was lost from the sample by an amount equivalent to the area between the curve and the 5 g/L line. This amounts to approximately 50 g of kaolinite lost from the sample. The last 2 effluent concentrations were lower than 5 g/L, resulting in an approximate 90 g of mass gained in the sample. The net result from this data show a mass retained of approximately 140 g. The mass of fines measured in the sample following this test was 130 g.

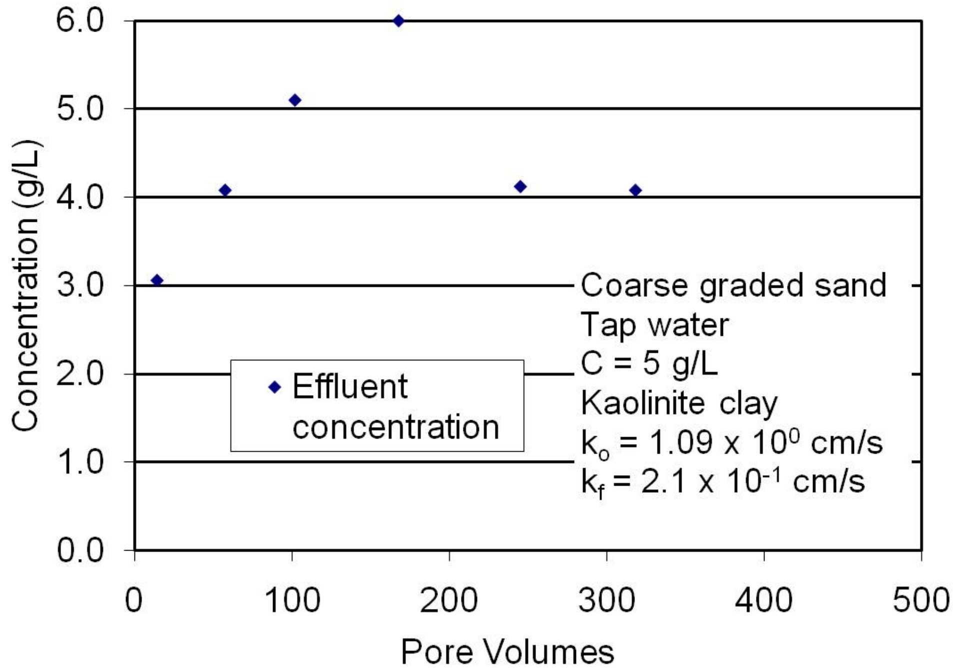

Figure 4.32 – Breakthrough curve – fines concentration in the effluent versus pore volumes for the test shown in Figure 4.29.

Further testing with kaolinite indicates that the rate of permeability change slows once breakthrough occurs. The French Drain sand initially contained approximately 3% fines, which was roughly 125 g. Figure 4.33 shows the results of a French Drain test with tap water and kaolinite, in which 155 g of fines were found to be trapped in the column following the test. The breakthrough curve (also shown in Figure 4.33) reaches its peak at roughly 40 pore volumes, which relates to 17% of the original sample permeability. The sample permeability leveled off at this point. The measured area between the inflow concentration of 5 g/L and the effluent concentration curve is 68 g of kaolinite prior to breakthrough and 8 g of kaolinite following breakthrough. Since no effluent concentration readings were higher than the inflow concentration, the net mass retained in the sample was approximately 76 g. This is higher than the estimated 30 g of kaolinite retained, which assumed the initial mass of fines in the sample was 125 g.

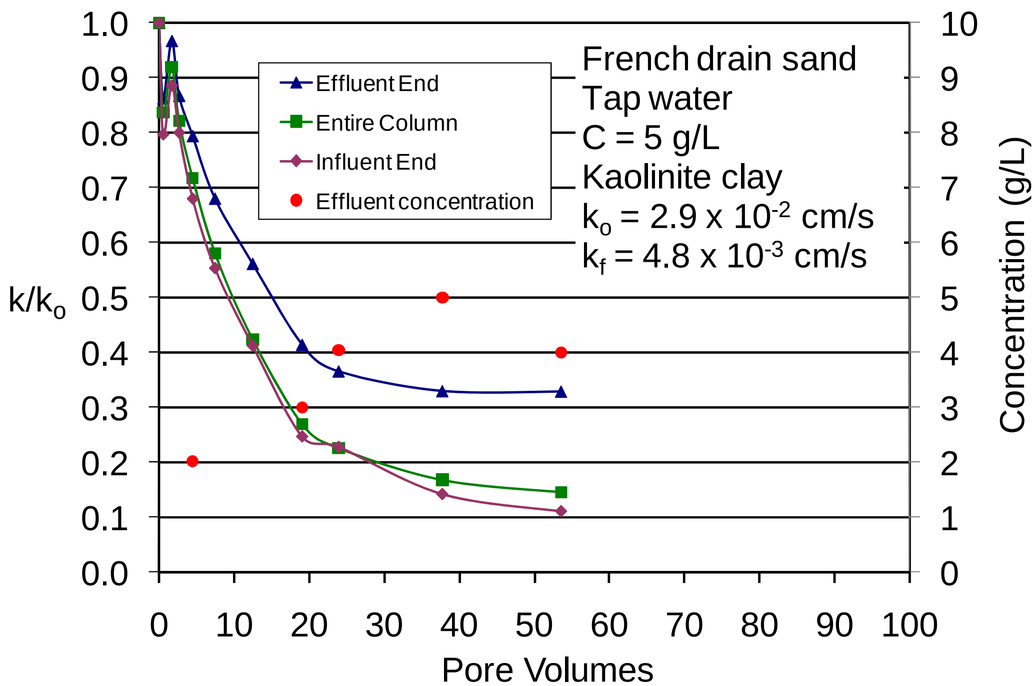

Figure 4.33 – Permeability reduction plotted with breakthrough curve (French Drain sand, kaolinite fines and tap water).

Tests on the Uniform sand present a similar finding. Figure 4.34 shows the kaolinite in tap water test result, in which 125 g of kaolinite were trapped in the column. The breakthrough curve is presented on the same graph. A lack of measurements makes it difficult to determine when equilibrium was reached. A concentration of 4 g/L was measured at only 9 pore volumes of flow, and 5 g/L was measured at 75 pore volumes of flow. If 75 pore volumes are taken to be the breakthrough point, the permeability results indicate a clear change in the rate of permeability reduction. The kaolinite mass retained in the sample prior to the point of breakthrough is approximately 97 g, calculated using the area above the curve. Approximately

40 g appears to have been lost from the sample following breakthrough, as the measured effluent concentration exceeded 5 g/L. The net result is that approximately 57 g of kaolinite appear to have been retained in the sample. As mentioned above, 125 g of kaolinite were measured in the sample following the test.

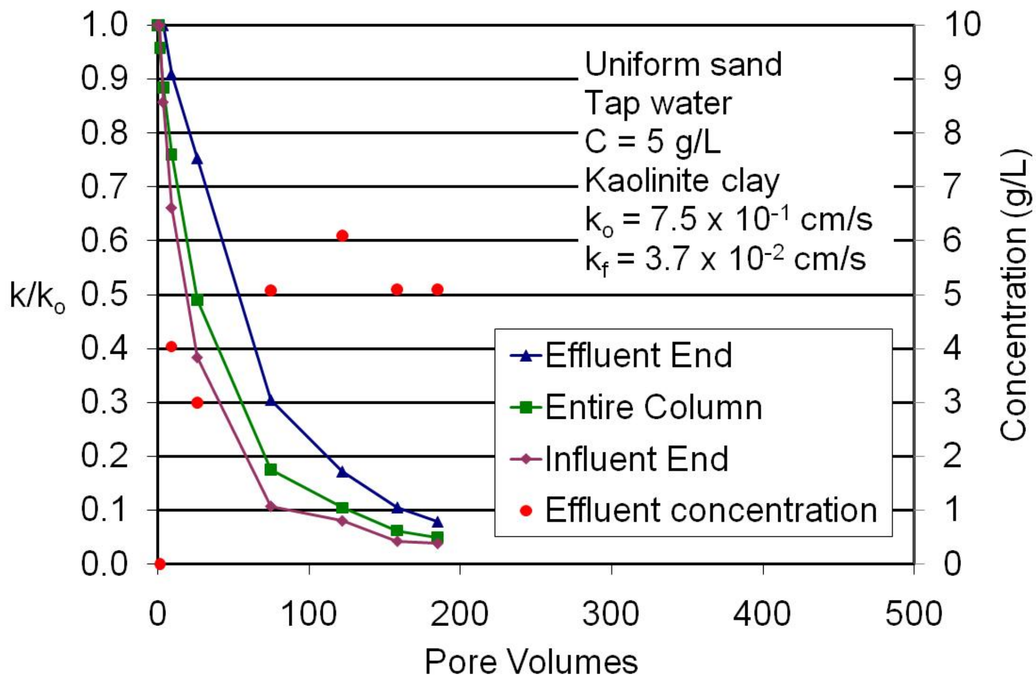

Figure 4.34 – Permeability reduction plotted with breakthrough curve (Uniform sand, kaolinite fines and tap water).

The test breakthrough curve for Battleford Till fines in French Drain sand and tap water are presented in Figure 4.35. The results indicate that the effluent concentrations in the breakthrough curve did not reach the influent concentration at any time during the test. This is not likely to be true. The mass of fines injected into the sample was 519 g, while the mass of fines found in the sample after the test run was 151 g (of which approximately 125 g were present in the French Drain sample prior to the test run). It is likely that errors were made while measuring the fines content of the effluent.

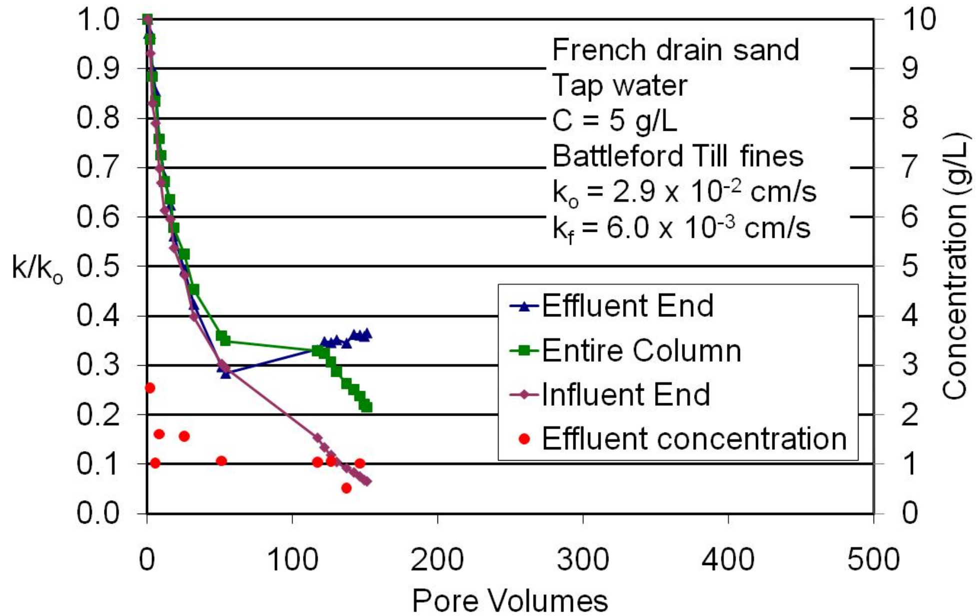

Figure 4.35 – Permeability reduction plotted with breakthrough curve (French Drain sand, Battleford Till fines and tap water).

The tap water test run and breakthrough curve combinations for the Uniform sand and the Coarse Graded sand are shown in Figure 4.36 and Figure 4.37. It appears that out of the three test runs, only the effluent from the Coarse Graded sand came close to reaching the influent concentration. This differs from the kaolinite test runs, where the influent concentration was reached in all three cases.

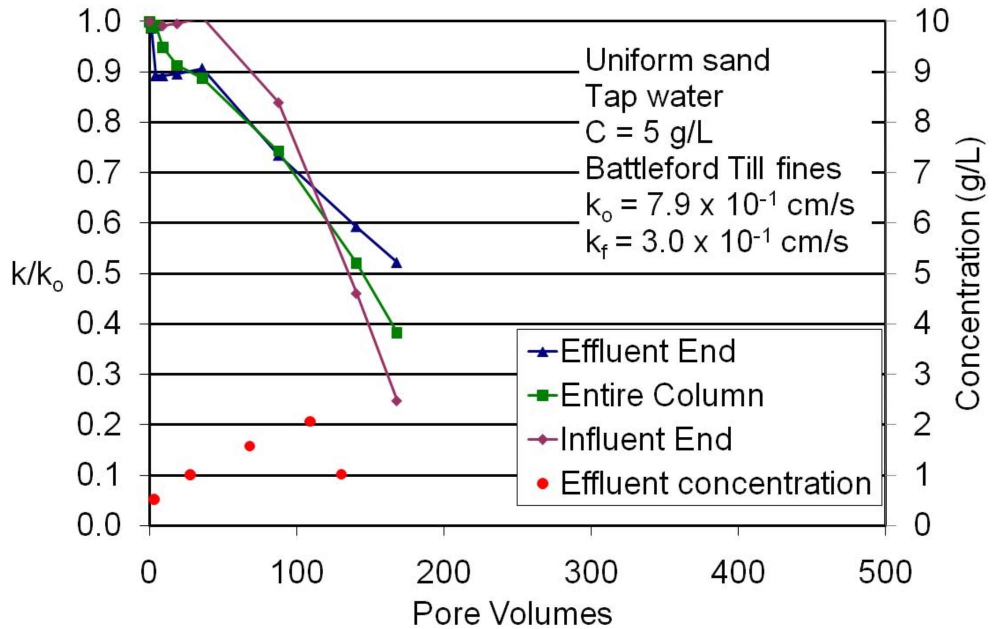

Figure 4.36 – Permeability reduction plotted with breakthrough curve (Uniform sand, Battleford Till fines and tap water).

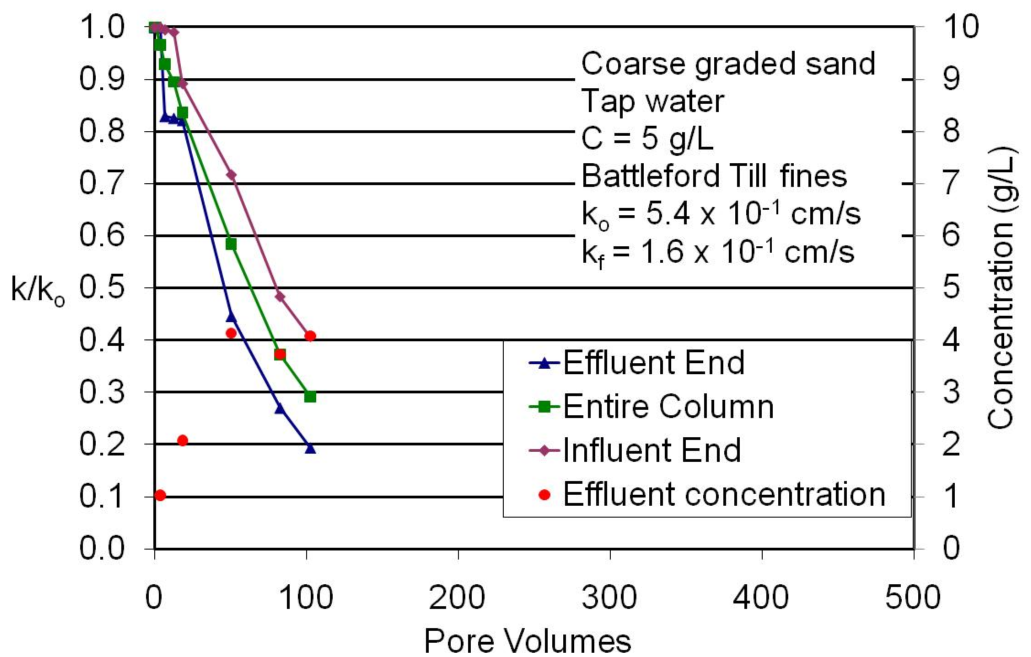

Figure 4.37 – Permeability reduction plotted with breakthrough curve (Coarse Graded sand, Battleford Till fines and tap water).

There are only minor differences between the kaolinite and Battleford Till fines in terms of particle size distribution and percentage of clay sized particles. It is thus difficult to explain the differing test results. Since a similar mass of the two types of fines were sent through the filter samples, the Battleford Till fines effluent must have reached influent concentrations. Errors involved in testing the effluent concentrations are a more likely explanation for the difference.

The salt water test with the same influent concentration (Figure 4.38) shows an incoherent breakthrough curve that never reaches influent concentration. There appears to be a large error in the assumption that the salt concentration of the effluent remained unchanged from the influent concentration. Perhaps the volume of effluent collected was too small to accurately apply a correction for the salt concentration.

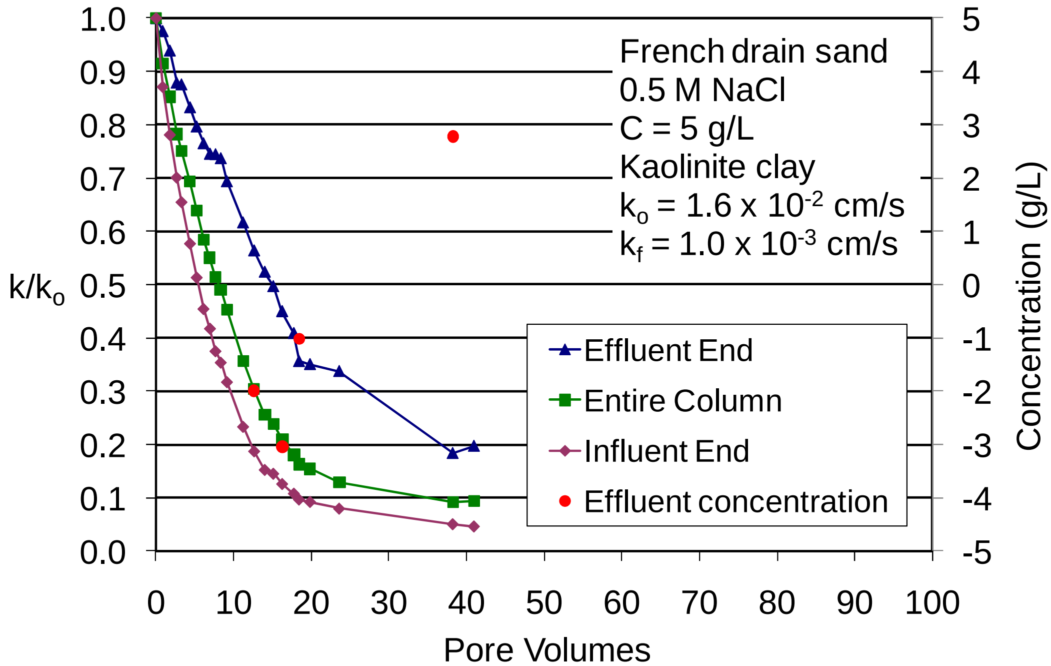

Figure 4.38 – Permeability reduction plotted with breakthrough curve (French Drain sand, kaolinite fines and salt water).

All of the results in this chapter have been presented in relative terms. The permeabilities throughout the tests have been compared to the original permeability of the granular sample. Figure 4.39 presents the kaolinite test results in terms of measured permeability. It is clear from this graph that there is a large benefit in long-term permeability when a coarse granular is chosen over a fine one.

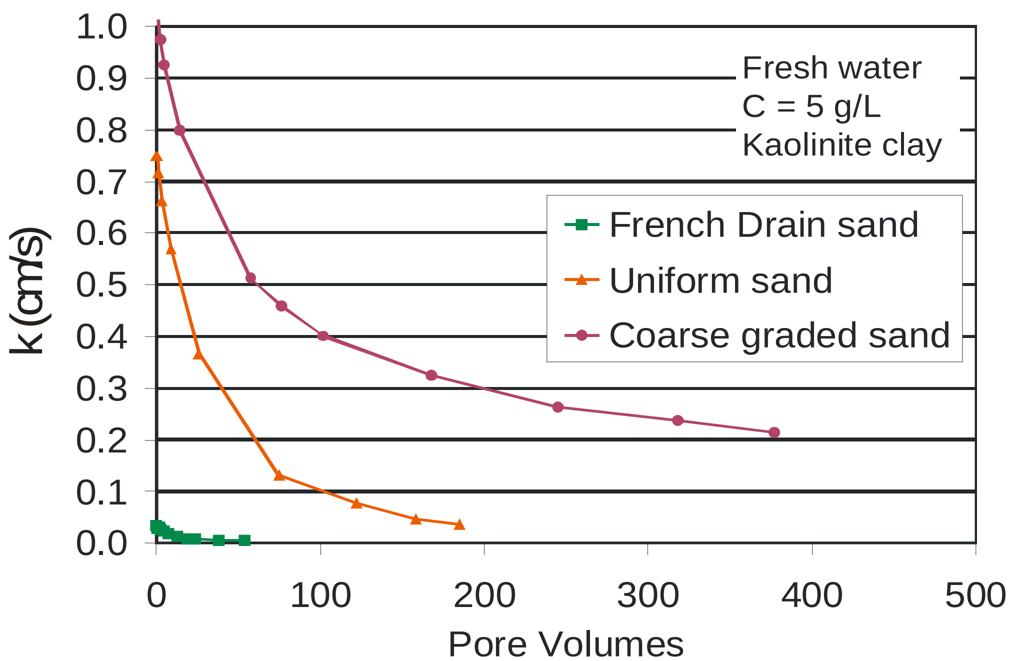

Figure 4.39 – Measured permeability under tap water conditions and kaolinite infiltration.

Table 4.11 shows average permeabilities for each granular material upon completion of the test runs (from final test program results only). For comparison, the first two columns of permeabilities were taken from Table 4.4. The table shows that permeabilities were reduced to approximately 20% of initial k, on average. Some of the test results with salt water in the Coarse Graded sand produced a higher average for that material. The approximate D_{10} size of the test materials following test runs is presented, calculated using equation 3.1. In all cases, the D_{10} size is estimated to be less than 0.075 mm, which is the sand/fines boundary. These calculations indicate that there should have been greater than 10% fines, by mass within the sample following the tests. The actual fines amount measured were mainly between 3 and 5%.

Table 4.11- Laboratory test program permeability results.

	Average Permeability (cm/s)						
Granular	**Hazen k value**	**k following self-filtration**	**k following test runs**	**Average % of k_o reached**	**Permeant**	**D_{10} prior to test runs (mm)**	**Approximate D_{10} following test runs (mm)**
French Drain Sand	0.040	0.026	0.006	25%	Fresh water	0.2	0.008
		0.015	0.003	16%	0.5 M NaCl		0.005
Uniform Sand	0.36	0.75	0.18	23%	Fresh water	0.6	0.042
		0.67	0.10	20%	0.5 M NaCl		0.032
Coarse Graded Sand	0.49	0.76	0.16	21%	Fresh water	0.7	0.040
		0.40	0.17	35%	0.5 M NaCl		0.041

4.7 Current Results Compared with Past Studies

The research project involved a literature review of filter design. The results of the review indicate that a coarser design would likely retain filtration capability. Past laboratory test results show coarser filters successfully protected many fine soils (even dispersive soils). The conservative design guidelines currently presented by the USDA are based on work by Sherard and Dunnigan (1989). These guidelines do not consider the earlier work by Sherard et al. (1984b) (in the same laboratory test program) which found that "(f)or silts and clays with significant sand content (d_{85} of 0.1-0.5 mm), the existing main filter criterion, $D_{15}/d_{85} < 5$ is conservative and reasonable."

These past laboratory test programs did not consider the clogging potential of filters. More recent studies looked to determine the loss in effectiveness of granular drains/filters due to fines infiltration. The results of the current test program, along with past study data, show that the permeability of granular filters can be irreversibly reduced to a significant degree. The current test program shows that a coarser granular filter allows a much higher volume of fines to pass through than a traditionally designed filter before an equivalent relative reduction in permeability is reached. A coarse filter retains a greater overall permeability than a fine filter after becoming clogged. It is thus intuitive that a coarse material should be used in place of a fine material for the filter. This is acceptable as long as there will be no detrimental effect on the base soils next to the constructed filter and there is some means to collect and remove fines from the system.

Although the stability of base soils was not tested in the current program, the literature indicates that only a very coarse filter would cause continual erosion of a typical base soil. According to Foster and Fell (2001), a filter soil designed with a D_{15} size less than 9 times the d_{95} of the base soil will not fail in providing stability to the base soil. Sherard et al. (1984b) found filter boundary sizes, D_{15B} that were, on average, 25 times the d_{85} of the fine base soils tested. It can be speculated that the d_{95} of many of these soils was not significantly different than the soil's d_{85} value. Thus there is some inconsistency in the literature as to the maximum D_{15} size that will protect a fine base soil from significant erosion.

The "filter opening size", originally presented by Sherard et al (1984a), is approximated by D_{15} / 9. Recall that findings from previous studies have found that almost all particles that pass through a filter are smaller than D_{15} / 9 (Sherard et al, 1984a). Increasing the opening size of the filter by making it coarser may allow many more particles to enter the drain. A D_{15} of 0.7 mm allows only clay and silt size particles to enter (D_{15} / 9 = 0.078 mm). Intuitively, this may increase the "zone of self-filtration" (see Figure 2.5) and cause more fines to enter the drain; however, a coarser drain could handle the extra mass while retaining higher permeability.

In fact, the zone of self-filtration within a base soil may be quite limited, creating an upper bound to the amount of fines available to flow through a drain. In the model presented in Chapter 2 and developed by Lafleur et al. (1989), the size of the layer affected by self-filtration can be estimated for a broadly graded soil next to a filter. A typical glacial till soil (Figure 4.40) could have a d_{100} size of 30 mm and a d_0 size of 0.001 mm (~5% clay sized particles). The calculated coefficient of broadness, C_B, for this soil would be 78, after using the traditional method to design the filter. The allowable retention ratio, D_{15} / d_{85}, will not be 4, as with coarser base soils, but would likely be around 1. That, in turn, makes the m value 6 and the H_o value (thickness of base soil affected) 180 mm. In comparison, a traditionally designed filter for a base soil with d_{100} equal to 40 mm and d_0 equal to 0.006 mm returned an H_o value of 120 mm.

These estimates show that, under normal circumstances, it is only the soil immediately adjacent the filter that will be affected by particle movement and rearrangement. It is intuitive that little instability could result from particle movement within such a limited volume of soil. However, a significant concentration of salinity in the groundwater followed by infiltration of fresh water has the potential to affect particle release in the base soil. This could directly affect the extent of particle movement both within the drain and the base soil. This issue is recommended for further study.

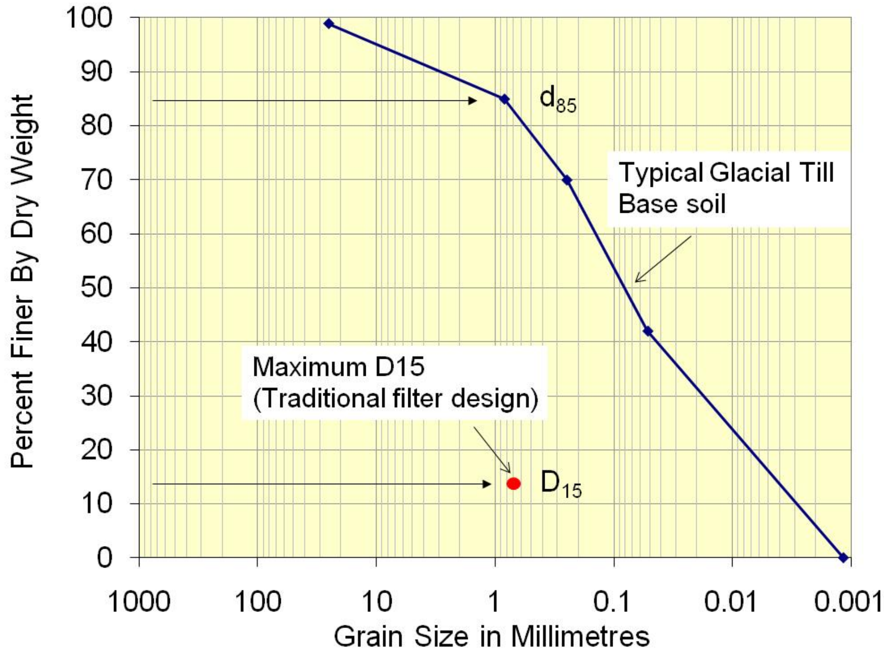

Figure 4.40 – Example of a glacial till with D_{15} from traditional filter design.

One of the objectives was to determine whether "real world" silt and clay particles would clog a drain faster in a brine environment. It was found that salinity made little difference to the rate of clogging, likely due to the high proportion of silt, and low proportion of high activity clay minerals, in the fine soils used. When relatively fresh groundwater (low total dissolved solids – TDS) is replaced by groundwater with a high salinity content (sodium chloride, for example), there is no detrimental effect on the erodibility of the soil. Calcium and magnesium ions common to clay exchange sites in glacial tills are "kicked off" and replaced with sodium ions. The work of Arulanandan et al. (1975) has shown that fines from such a soil are highly unlikely to erode as long as the pore fluid remains saline. However, when the saline pore fluid is replaced by fresh water (or less saline pore fluid), the erosion rate can increase. The current study indicates that pore-water salinity seems to affect deposition within drains only in the case of clay minerals. A drain installed next to a base soil containing a high proportion of active clays may clog faster in an environment where brine cycles with fresh water.

CHAPTER 5 CONCLUSIONS

5.1 Results of the Test Program

The results of the study suggest that traditionally designed filters are inadequate for drains that are intended for long term geoenvironmental decommissioning. This has led to the opportunity to present an alternative coarse granular filter sand design. Coarser filters would lead to more effective drainage systems with larger zones of influence and reliable drawdown in the adjacent soils. These drains would also prevent instability in adjacent base soils.

The general findings of the study include:

- Permeabilities of all sands decreased by roughly an order of magnitude when injected with a high concentration of fines (5 g/L).
- Permeability decreased to a lesser extent in the graded sands when injected with a low concentration of fines (1 g/L).
- Low concentrations of fines caused permeability to decrease slower in terms of pore volumes of flow but usually caused a similar rate of permeability reduction when considering pore volumes of fines injected (i.e. mass of fines injected ultimately determined the rate of permeability decrease).
- Salinity in the pore water had a minimal impact on the rate of permeability reduction.
- All sands seemed to retain a similar percentage of fines (in many cases, the fines were distributed relatively evenly across the column).
- In some cases, the point of breakthrough was shown to coincide with permeability beginning to level off (i.e. permeability did not decrease further to a great extent following breakthrough).

- Coarse granular soils retained greater absolute permeability following fines infiltration.
- Coarse granular soils allowed a much greater flow-through volume of fines.
- A graded sand/gravel mix may be better at retaining permeability than a filter of uniform size.

5.2 Granular Filter Design for Environmental Containment Applications

The main research objective was to develop recommendations for the design of a granular drainage soil to be used for future active containment installations at industrial facilities. It is proposed that a material similar to the Coarse Graded sand be used in the design of any environmental drainage system where low gradient groundwater type flow is expected. Such a sand, even when clogged, has a greater ability to maintain flow than a fine sand. This means that a drain installed with granular that meets the proposed design should provide effective drawdown in the base soil for an extended period of time.

Consider that the existing state of practice in filter design accepts two granular materials with quite different D_{15} sizes. In the case of a base soil in soil group 2 (see Figure 3.1 in Chapter 3), the acceptable filter D_{15} could range from 0.14 mm to 0.7 mm (a ratio of 5). The current study has shown the large difference in performance between granular materials with D_{15} sizes ranging from 0.3 mm (French Drain sand) to 0.9 mm (Coarse Graded sand) – a ratio of only 3. If the maintenance of an acceptably high permeability is the goal of a granular drainage system, and it can be expected that the system will lose an order of magnitude of its permeability during operation, it is proposed that the fine end of the current design band is not acceptable. In the case of a heterogeneous layered base soil, such fine granular drainage soils may have the potential to reach a permeability at or below that of the coarse base soil layers. If this occurs, the drainage soil may no longer perform its intended function.

The proposed design is presented in Figure 5.1. The fine end of the design band is slightly coarser than the French Drain sand used in the current study. The design is applicable for any base soil with a d_{85} between 0.075 and 0.5 mm. Many silt tills fall within this base soil band. For base soils with d_{85} finer than 0.075 mm, it is unclear whether the proposed design band would succeed in providing stability to a dispersive soil.

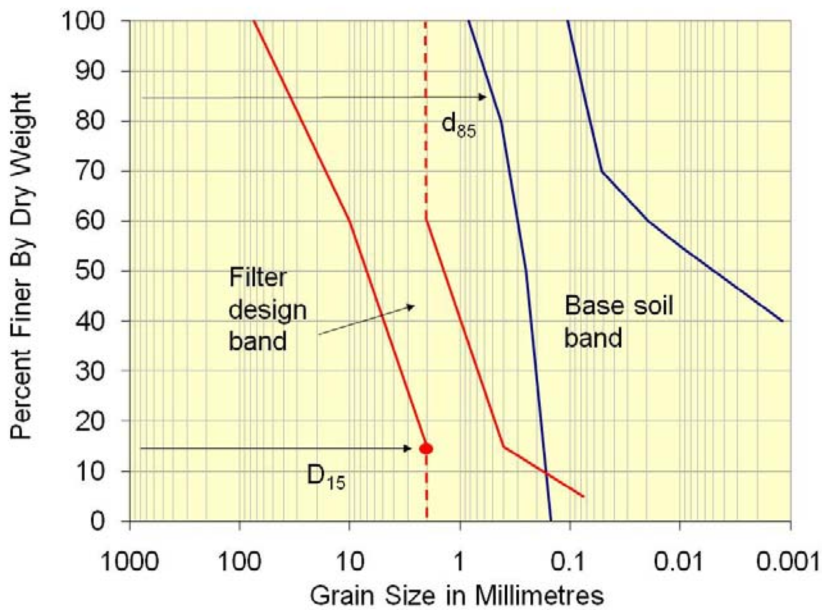

Figure 5.1 – Proposed design band – filter sand for environmental drainage applications.

The proposed design is a graded sand and gravel filter. The requirements are as follows:

- The D_{15} size is between 0.4 and 2.0 mm.
- The D_{60} size is between 2.0 and 10.0 mm.
- The maximum particle size is 75 mm.

- The maximum allowable proportion of fines in the filter material is 5%.

The design is simple, with few requirements. The parts of the design retained from the traditional design in the National Engineering Handbook (NRCS, 1994) are as follows:

- The ratio between maximum and minimum sizes at every point between D_{15} and D_{60} (5).
- The maximum particle size.
- The allowable proportion of fines in the filter material.

For base soils with d_{85} coarser than 0.5 mm, the same design is recommended, with the following amendment: the filter design band is moved to the left, by changing the maximum D_{15} value according to Terzaghi's retention criteria concept:

$$D_{15} / d_{85} < 4 \tag{5.1}$$

5.3 Constructability Requirements

Granular drains developed using the recommended design would require the same amount of aggregate preparation that was common under the previous design guidelines. This may include screening and mixing sands to fit within the design band.

The recommended design will deliver higher flow rates than the traditional design. The volume of fines passing through the drain material will depend on factors such as the salinity of the water, and the fines available in the zone of the base soil delivering the flow. Overall, however, the fines volume will likely be much higher than in the traditional design. These fines will have to be removed from sumps (pump wells) installed within the drain. A perforated pipe may be placed at the base of the drain. This would allow for removal of a greater volume of water and thus help to maintain a low head within the drain. If such a pipe were installed, it may require routine flushing to remove a buildup of fines. If the drain is collecting water with high salinity content, the use of fresh water for flushing is beneficial, as it will encourage fine particles within clogged portions of the drain to become entrained in the flow. This, in turn, can increase the permeability of the drain.

5.4 Recommendations

The laboratory study has shown that a coarse material should be used in place of a fine material for a filter. This is preferable as long as there will be no detrimental effect on the base soils next to the constructed filter and there is some means to collect and remove fines from the system. The recommended design for filters to be used in environmental containment applications was presented in Section 5.2.

The literature suggests that a significant concentration of salinity in the groundwater followed by infiltration of fresh water has the potential to affect particle release in the base soil, regardless of the groundwater gradient. This could directly affect the extent of particle movement both within the filter and the base soil. The fine soils used in the current study did not contain a sufficient portion of active clay minerals to be affected by brine. This issue is central in the recommended for further study.

5.5 Recommendations for Future Study

The summary of recommendations for future study includes:

- determination of the erodibility of potential base soils under conditions of cycled brine with fresh water;
- determination of the thickness of base soil (adjacent a filter) from which fine particles are allowed to migrate under conditions of cycled brine with fresh water;
- determination of the gradient at which point the filtration component of the design becomes important (i.e. the pressure required to mobilize base particles and induce "self-filtration").
- implementation of a test section in a groundwater environment, with a plan to collect and remove fine soil and monitor head levels around the drain.

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APPENDIX A

SOIL WATER CHARACTERISTIC CURVE (SWCC) DATA

Uniform		French Drain		Coarse Graded	
Press (kPa)	VWC	Press (kPa)	VWC	Press (kPa)	VWC
1.00E-02	4.00E-01	1.00E-02	2.59E-01	1.00E-02	3.06E-01
2.78E-02	4.00E-01	2.78E-02	2.45E-01	2.78E-02	2.48E-01
7.74E-02	4.00E-01	7.74E-02	2.22E-01	7.74E-02	1.90E-01
1.11E-01	4.00E-01	1.11E-01	2.12E-01	1.11E-01	1.69E-01
2.15E-01	4.00E-01	2.15E-01	1.91E-01	2.15E-01	1.31E-01
5.99E-01	1.74E-01	5.99E-01	1.55E-01	5.99E-01	7.40E-02
1.67E+00	2.35E-02	1.67E+00	1.17E-01	1.67E+00	2.60E-02
4.64E+00	3.03E-03	4.64E+00	7.17E-02	4.64E+00	4.27E-03
1.06E+01	3.03E-03	1.06E+01	2.33E-02	1.06E+01	4.27E-03
1.29E+01	3.03E-03	1.29E+01	1.67E-02	1.29E+01	4.27E-03
2.11E+01	3.03E-03	2.11E+01	5.74E-03	2.11E+01	4.27E-03
3.16E+01	3.03E-03	3.16E+01	1.93E-03	3.16E+01	4.27E-03
3.59E+01	3.03E-03	3.59E+01	1.16E-03	3.59E+01	4.27E-03
4.20E+01	3.03E-03	4.20E+01	8.36E-04	4.20E+01	4.27E-03
5.25E+01	3.03E-03	5.25E+01	8.36E-04	5.25E+01	4.27E-03
6.30E+01	3.03E-03	6.30E+01	8.36E-04	6.30E+01	4.27E-03
7.35E+01	3.03E-03	7.35E+01	8.36E-04	7.35E+01	4.27E-03
8.40E+01	3.03E-03	8.40E+01	8.36E-04	8.40E+01	4.27E-03
9.44E+01	3.03E-03	9.44E+01	8.36E-04	9.44E+01	4.27E-03
1.00E+02	3.03E-03	1.00E+02	8.36E-04	1.00E+02	4.27E-03

APPENDIX B

PARTICLE SIZE ANALYSES

Kaolinite – No salt

MASTERSIZER

Result: Analysis Report

Sample Details

Sample ID: Kaolinite
Run Number: 1
Measured: 20 Mar 2008 14:05PM
Sample File: [illegible]
Analysed: 20 Mar 2008 14:05PM
Sample Path: C:\SIZERS\DATA\
Result Source: Analysed
Sample Notes:

System Details

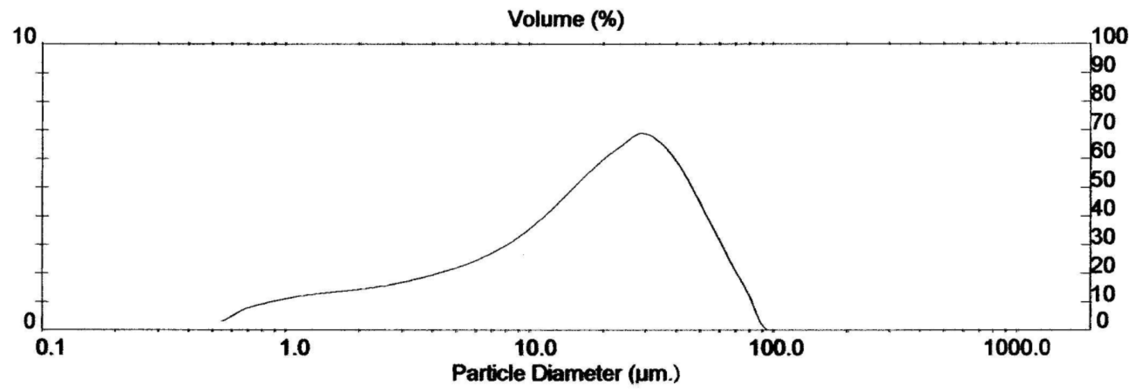
Range Lens: 300 mm
Beam Length: 2.40 mm
Sampler: MS1
Obscuration: 18.0 %
Presentation: 3OHD
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]
Analysis Model: Polydisperse
Residual: 0.517 %
Modifications: None

Result Statistics

Distribution Type: Volume
Concentration = 0.0166 %Vol
Density = 1.500 g / cub. cm
Specific S.A. = 0.6671 sq. m / g
Mean Diameters:
D (v, 0.1) = 2.17 um
D (v, 0.5) = 18.11 um
D (v, 0.9) = 48.51 um
D [4, 3] = 22.18 um
D [3, 2] = 6.00 um
Span = 2.559E+00
Uniformity = 7.967E-01

Size Low (um)	In %	Size High (um)	Under%
0.49	0.31	0.58	0.31
0.58	0.59	0.67	0.89
0.67	0.83	0.78	1.73
0.78	0.98	0.91	2.70
0.91	1.10	1.06	3.81
1.06	1.20	1.24	5.01
1.24	1.28	1.44	6.29
1.44	1.34	1.68	7.63
1.68	1.39	1.95	9.02
1.95	1.46	2.28	10.48
2.28	1.54	2.65	12.02
2.65	1.64	3.09	13.66
3.09	1.76	3.60	15.43
3.60	1.90	4.19	17.33
4.19	2.06	4.88	19.40
4.88	2.25	5.69	21.65
5.69	2.47	6.63	24.12
6.63	2.74	7.72	26.85
7.72	3.06	9.00	29.92
9.00	3.46	10.48	33.38
10.48	3.94	12.21	37.31
12.21	4.47	14.22	41.78
14.22	5.03	16.57	46.82
16.57	5.58	19.31	52.40
19.31	6.08	22.49	58.48

Size Low (um)	In %	Size High (um)	Under%
22.49	6.50	26.20	64.98
26.20	6.86	30.53	71.85
30.53	6.67	35.56	78.51
35.56	6.11	41.43	84.62
41.43	5.23	48.27	89.85
48.27	4.15	56.23	94.00
56.23	3.08	65.51	97.08
65.51	2.00	76.32	99.08
76.32	0.92	88.91	100.00
88.91	0.00	103.58	100.00
103.58	0.00	120.67	100.00
120.67	0.00	140.58	100.00
140.58	0.00	163.77	100.00
163.77	0.00	190.80	100.00
190.80	0.00	222.28	100.00
222.28	0.00	258.95	100.00
258.95	0.00	301.68	100.00
301.68	0.00	351.46	100.00
351.46	0.00	409.45	100.00
409.45	0.00	477.01	100.00
477.01	0.00	555.71	100.00
555.71	0.00	647.41	100.00
647.41	0.00	754.23	100.00
754.23	0.00	878.67	100.00



Kaolinite – Salt

MASTERSIZER

1 min

Result: Analysis Report

Sample Details

Sample ID: K-Salt2 | Run Number: 5 | Measured: 20 Mar 2008 14:39PM
Sample File: MARTYWET | Record Number: 4 | Analysed: 20 Mar 2008 14:39PM
Sample Path: C:\SIZERS\DATA\ | Result Source: Analysed
Sample Notes:

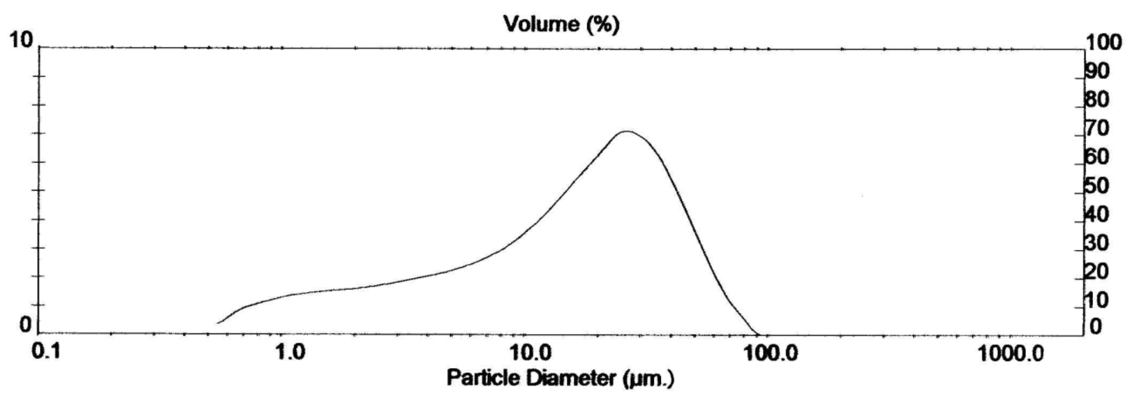
System Details

Range Lens: 300 mm | Beam Length: 2.40 mm | Sampler: MS1 | Obscuration: 19.7 %
Presentation: 3OHD | [Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]
Analysis Model: Polydisperse | Residual: 0.407 %
Modifications: None

Result Statistics

Distribution Type: Volume | Concentration = 0.0166 %Vol | Density = 1.500 g / cub. cm | Specific S.A. = 0.7381 sq. m / g
Mean Diameters: | D (v, 0.1) = 1.86 um | D (v, 0.5) = 16.74 um | D (v, 0.9) = 43.49 um
D [4, 3] = 20.12 um | D [3, 2] = 5.42 um | Span = 2.487E+00 | Uniformity = 7.877E-01

Size Low (um)	In %	Size High (um)	Under%	Size Low (um)	In %	Size High (um)	Under%
0.49	0.36	0.58	0.36	22.49	7.05	26.20	69.00
0.58	0.69	0.67	1.05	26.20	7.06	30.53	76.05
0.67	0.98	0.78	2.03	30.53	6.61	35.56	82.67
0.78	1.15	0.91	3.17	35.56	5.74	41.43	88.41
0.91	1.29	1.06	4.47	41.43	4.57	48.27	92.99
1.06	1.41	1.24	5.87	48.27	3.30	56.23	96.29
1.24	1.49	1.44	7.36	56.23	2.11	65.51	98.40
1.44	1.54	1.68	8.90	65.51	1.14	76.32	99.54
1.68	1.59	1.95	10.49	76.32	0.46	88.91	100.00
1.95	1.64	2.28	12.13	88.91	0.00	103.58	100.00
2.28	1.72	2.65	13.84	103.58	0.00	120.67	100.00
2.65	1.81	3.09	15.66	120.67	0.00	140.58	100.00
3.09	1.92	3.60	17.58	140.58	0.00	163.77	100.00
3.60	2.03	4.19	19.60	163.77	0.00	190.80	100.00
4.19	2.16	4.88	21.76	190.80	0.00	222.28	100.00
4.88	2.32	5.69	24.08	222.28	0.00	258.95	100.00
5.69	2.51	6.63	26.59	258.95	0.00	301.68	100.00
6.63	2.75	7.72	29.34	301.68	0.00	351.46	100.00
7.72	3.07	9.00	32.41	351.46	0.00	409.45	100.00
9.00	3.48	10.48	35.89	409.45	0.00	477.01	100.00
10.48	3.98	12.21	39.87	477.01	0.00	555.71	100.00
12.21	4.57	14.22	44.44	555.71	0.00	647.41	100.00
14.22	5.20	16.57	49.64	647.41	0.00	754.23	100.00
16.57	5.85	19.31	55.49	754.23	0.00	878.67	100.00
19.31	6.47	22.49	61.95				



Battleford Till fines – No salt

MASTERSIZER

Result: Analysis Report

Sample Details

Sample ID: BT
Sample File: MARTYWET
Sample Path: C:\SIZERS\DATA\
Sample Notes:

Run Number: 3
Record Number: 2

Measured: 20 Mar 2008 14:22PM
Analysed: 20 Mar 2008 14:22PM
Result Source: Analysed

System Details

Range Lens: 300 mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS1

Obscuration: 26.5 %
Residual: 0.259 %

Result Statistics

Distribution Type: Volume
Mean Diameters:
D [4, 3] = 30.92 um

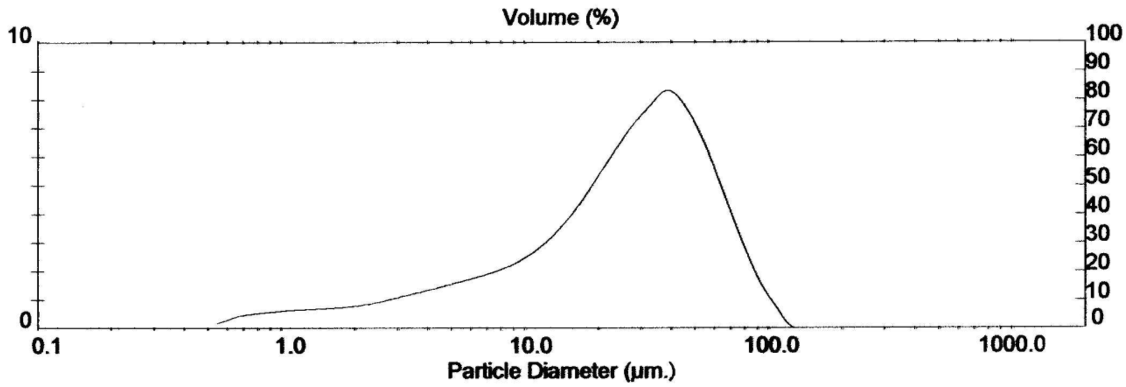
Concentration = 0.0385 %Vol
D (v, 0.1) = 4.06 um
D [3, 2] = 9.02 um

Density = 1.500 g / cub. cm
D (v, 0.5) = 27.31 um
Span = 2.136E+00

Specific S.A. = 0.4437 sq. m / g
D (v, 0.9) = 62.40 um
Uniformity = 6.614E-01

Size Low (um)	In %	Size High (um)	Under%
0.49	0.18	0.58	0.18
0.58	0.35	0.67	0.54
0.67	0.49	0.78	1.03
0.78	0.56	0.91	1.58
0.91	0.62	1.06	2.20
1.06	0.66	1.24	2.86
1.24	0.69	1.44	3.55
1.44	0.72	1.68	4.26
1.68	0.76	1.95	5.02
1.95	0.82	2.28	5.84
2.28	0.91	2.65	6.75
2.65	1.04	3.09	7.79
3.09	1.18	3.60	8.97
3.60	1.31	4.19	10.28
4.19	1.45	4.88	11.73
4.88	1.60	5.69	13.33
5.69	1.75	6.63	15.08
6.63	1.91	7.72	17.00
7.72	2.12	9.00	19.12
9.00	2.40	10.48	21.52
10.48	2.78	12.21	24.29
12.21	3.28	14.22	27.57
14.22	3.92	16.57	31.49
16.57	4.69	19.31	36.18
19.31	5.54	22.49	41.73

Size Low (um)	In %	Size High (um)	Under%
22.49	6.40	26.20	48.13
26.20	7.18	30.53	55.31
30.53	7.82	35.56	63.12
35.56	8.30	41.43	71.42
41.43	7.84	48.27	79.26
48.27	6.84	56.23	86.11
56.23	5.48	65.51	91.58
65.51	3.97	76.32	95.55
76.32	2.54	88.91	98.09
88.91	1.37	103.58	99.46
103.58	0.54	120.67	100.00
120.67	0.00	140.58	100.00
140.58	0.00	163.77	100.00
163.77	0.00	190.80	100.00
190.80	0.00	222.28	100.00
222.28	0.00	258.95	100.00
258.95	0.00	301.68	100.00
301.68	0.00	351.46	100.00
351.46	0.00	409.45	100.00
409.45	0.00	477.01	100.00
477.01	0.00	555.71	100.00
555.71	0.00	647.41	100.00
647.41	0.00	754.23	100.00
754.23	0.00	878.67	100.00



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Mastersizer S long bed Ver. 2.19
Serial Number: MAL300050

p. 4
20 Mar 08 14:22

Battleford Till fines – Salt

MASTERSIZER

Result: Analysis Report

Sample Details

Sample ID: BT-Salt 2
Sample File:
Sample Path: C:\SIZERS\DATA\
Sample Notes:

Run Number: 9

Measured: 20 Mar 2008 14:53PM
Analysed: 20 Mar 2008 14:53PM
Result Source: Analysed

System Details

Range Lens: 300 mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS1

Obscuration: 20.2 %
Residual: 0.319 %

Result Statistics

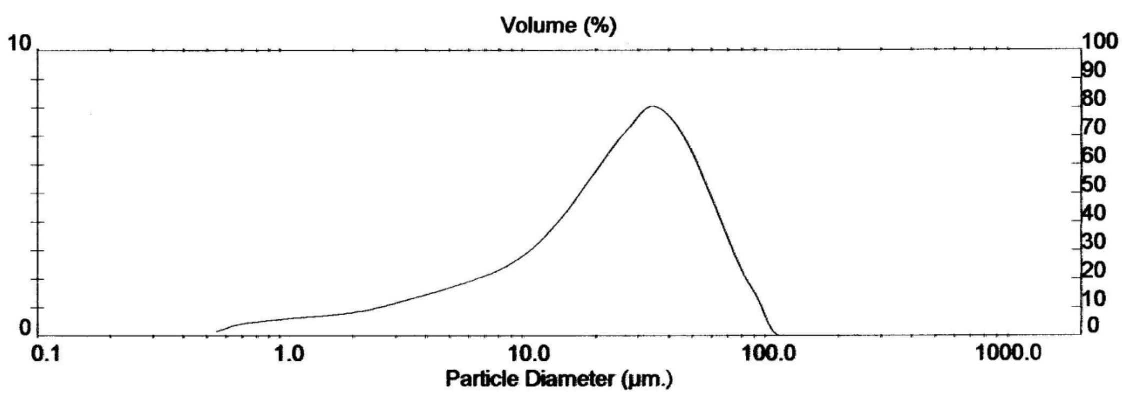
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 28.55 um

Concentration = 0.0274 %Vol
D (v, 0.1) = 3.96 um
D [3, 2] = 8.82 um

Density = 1.500 g / cub. cm
D (v, 0.5) = 24.89 um
Span = 2.182E+00

Specific S.A. = 0.4534 sq. m / g
D (v, 0.9) = 58.28 um
Uniformity = 6.734E-01

Size Low (um)	In %	Size High (um)	Under%	Size Low (um)	In %	Size High (um)	Under%
0.49	0.17	0.58	0.17	22.49	6.75	26.20	52.34
0.58	0.33	0.67	0.50	26.20	7.42	30.53	59.76
0.67	0.46	0.78	0.96	30.53	8.00	35.56	67.76
0.78	0.53	0.91	1.48	35.56	7.82	41.43	75.59
0.91	0.59	1.06	2.07	41.43	7.14	48.27	82.73
1.06	0.64	1.24	2.71	48.27	6.05	56.23	88.78
1.24	0.68	1.44	3.39	56.23	4.72	65.51	93.49
1.44	0.73	1.68	4.12	65.51	3.33	76.32	96.82
1.68	0.78	1.95	4.90	76.32	2.07	88.91	98.89
1.95	0.86	2.28	5.77	88.91	1.06	103.58	99.95
2.28	0.98	2.65	6.74	103.58	0.05	120.67	100.00
2.65	1.12	3.09	7.86	120.67	0.00	140.58	100.00
3.09	1.27	3.60	9.13	140.58	0.00	163.77	100.00
3.60	1.42	4.19	10.55	163.77	0.00	190.80	100.00
4.19	1.58	4.88	12.13	190.80	0.00	222.28	100.00
4.88	1.75	5.69	13.88	222.28	0.00	258.95	100.00
5.69	1.93	6.63	15.81	258.95	0.00	301.68	100.00
6.63	2.13	7.72	17.94	301.68	0.00	351.46	100.00
7.72	2.39	9.00	20.33	351.46	0.00	409.45	100.00
9.00	2.73	10.48	23.07	409.45	0.00	477.01	100.00
10.48	3.17	12.21	26.24	477.01	0.00	555.71	100.00
12.21	3.74	14.22	29.98	555.71	0.00	647.41	100.00
14.22	4.42	16.57	34.40	647.41	0.00	754.23	100.00
16.57	5.19	19.31	39.60	754.23	0.00	878.67	100.00
19.31	5.99	22.49	45.59				



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Mastersizer S long bed Ver. 2.19
Serial Number: MAL300050

p. 9
20 Mar 08 14:54

Regina Clay – No salt

MASTERSIZER

Result: Analysis Report

Sample Details

Sample ID: RC	Run Number: 2	Measured: 20 Mar 2008 14:17PM
Sample File: MARTYWET	Record Number: 1	Analysed: 20 Mar 2008 14:18PM
Sample Path: C:\SIZERS\DATA\		Result Source: Analysed
Sample Notes:		

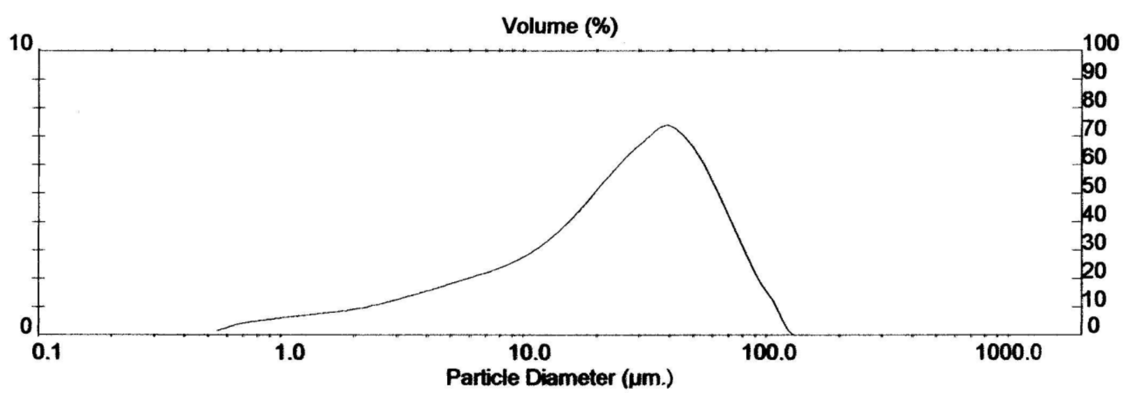
System Details

Range Lens: 300 mm	Beam Length: 2.40 mm	Sampler: MS1	Obscuration: 25.7 %
Presentation: 3OHD	[Particle R.I. = (1.5295, 0.1000);	Dispersant R.I. = 1.3300]	
Analysis Model: Polydisperse			Residual: 0.309 %
Modifications: None			

Result Statistics

Distribution Type: Volume	Concentration = 0.0350 %Vol	Density = 1.500 g / cub. cm	Specific S.A. = 0.4651 sq. m / g
Mean Diameters:	D (v, 0.1) = 3.67 um	D (v, 0.5) = 25.79 um	D (v, 0.9) = 64.92 um
D [4, 3] = 30.68 um	D [3, 2] = 8.60 um	Span = 2.375E+00	Uniformity = 7.412E-01

Size Low (um)	In %	Size High (um)	Under%	Size Low (um)	In %	Size High (um)	Under%
0.49	0.17	0.58	0.17	22.49	5.92	26.20	50.64
0.58	0.33	0.67	0.49	26.20	6.50	30.53	57.15
0.67	0.46	0.78	0.95	30.53	6.98	35.56	64.13
0.78	0.54	0.91	1.50	35.56	7.37	41.43	71.50
0.91	0.62	1.06	2.11	41.43	7.07	48.27	78.57
1.06	0.68	1.24	2.80	48.27	6.37	56.23	84.94
1.24	0.74	1.44	3.54	56.23	5.34	65.51	90.28
1.44	0.80	1.68	4.34	65.51	4.12	76.32	94.41
1.68	0.87	1.95	5.20	76.32	2.89	88.91	97.30
1.95	0.96	2.28	6.16	88.91	1.78	103.58	99.07
2.28	1.07	2.65	7.23	103.58	0.90	120.67	99.97
2.65	1.22	3.09	8.45	120.67	0.03	140.58	100.00
3.09	1.37	3.60	9.82	140.58	0.00	163.77	100.00
3.60	1.53	4.19	11.35	163.77	0.00	190.80	100.00
4.19	1.70	4.88	13.04	190.80	0.00	222.28	100.00
4.88	1.87	5.69	14.91	222.28	0.00	258.95	100.00
5.69	2.04	6.63	16.95	258.95	0.00	301.68	100.00
6.63	2.23	7.72	19.18	301.68	0.00	351.46	100.00
7.72	2.44	9.00	21.63	351.46	0.00	409.45	100.00
9.00	2.71	10.48	24.34	409.45	0.00	477.01	100.00
10.48	3.04	12.21	27.38	477.01	0.00	555.71	100.00
12.21	3.47	14.22	30.85	555.71	0.00	647.41	100.00
14.22	4.00	16.57	34.85	647.41	0.00	754.23	100.00
16.57	4.61	19.31	39.45	754.23	0.00	878.67	100.00
19.31	5.27	22.49	44.72				



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Mastersizer S long bed Ver. 2.19
Serial Number: MAL300050

Regina Clay – Salt

MASTERSIZER

Result: Analysis Report

Sample Details

Sample ID: RC-Salt
Sample File: MARTYWET
Sample Path: C:\SIZERS\DATA\
Sample Notes:

Run Number: 6
Record Number: 5

Measured: 20 Mar 2008 14:45PM
Analysed: 20 Mar 2008 14:45PM
Result Source: Analysed

System Details

Range Lens: 300 mm
Presentation: 3OHD
Analysis Model: Polydisperse
Modifications: None

Beam Length: 2.40 mm
[Particle R.I. = (1.5295, 0.1000); Dispersant R.I. = 1.3300]

Sampler: MS1

Obscuration: 28.6 %
Residual: 0.274 %

Result Statistics

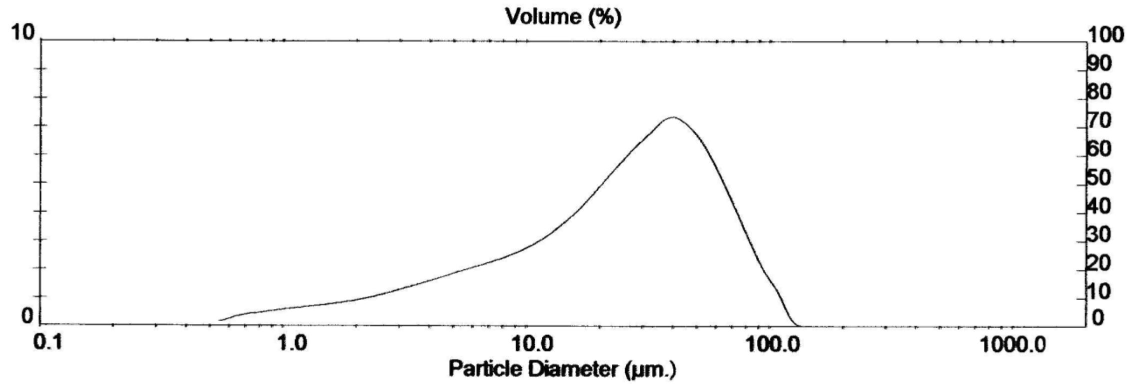
Distribution Type: Volume
Mean Diameters:
D [4, 3] = 31.13 um

Concentration = 0.0400 %Vol
D (v, 0.1) = 3.68 um
D [3, 2] = 8.69 um

Density = 1.500 g / cub. cm
D (v, 0.5) = 26.15 um
Span = 2.385E+00

Specific S.A. = 0.4601 sq. m / g
D (v, 0.9) = 66.05 um
Uniformity = 7.466E-01

Size Low (um)	In %	Size High (um)	Under%	Size Low (um)	In %	Size High (um)	Under%
0.49	0.16	0.58	0.16	22.49	5.74	26.20	50.07
0.58	0.31	0.67	0.47	26.20	6.34	30.53	56.42
0.67	0.44	0.78	0.91	30.53	6.87	35.56	63.29
0.78	0.52	0.91	1.43	35.56	7.33	41.43	70.62
0.91	0.60	1.06	2.02	41.43	7.13	48.27	77.75
1.06	0.66	1.24	2.68	48.27	6.49	56.23	84.24
1.24	0.73	1.44	3.41	56.23	5.50	65.51	89.74
1.44	0.79	1.68	4.20	65.51	4.29	76.32	94.03
1.68	0.87	1.95	5.07	76.32	3.03	88.91	97.06
1.95	0.96	2.28	6.03	88.91	1.89	103.58	98.95
2.28	1.09	2.65	7.12	103.58	0.98	120.67	99.93
2.65	1.24	3.09	8.36	120.67	0.07	140.58	100.00
3.09	1.41	3.60	9.77	140.58	0.00	163.77	100.00
3.60	1.57	4.19	11.34	163.77	0.00	190.80	100.00
4.19	1.74	4.88	13.08	190.80	0.00	222.28	100.00
4.88	1.91	5.69	14.99	222.28	0.00	258.95	100.00
5.69	2.09	6.63	17.08	258.95	0.00	301.68	100.00
6.63	2.26	7.72	19.34	301.68	0.00	351.46	100.00
7.72	2.46	9.00	21.80	351.46	0.00	409.45	100.00
9.00	2.70	10.48	24.51	409.45	0.00	477.01	100.00
10.48	3.01	12.21	27.52	477.01	0.00	555.71	100.00
12.21	3.39	14.22	30.91	555.71	0.00	647.41	100.00
14.22	3.88	16.57	34.79	647.41	0.00	754.23	100.00
16.57	4.45	19.31	39.24	754.23	0.00	878.67	100.00
19.31	5.09	22.49	44.33				



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Mastersizer S long bed Ver. 2.19
Serial Number: MAL300050

p. 7
20 Mar 08 14:45

APPENDIX C

LABORATORY TEST RESULTS

French Drain Sand with Kaolinite

Constant HeadTest									10.0984										
		Test AB	(2nd column)					Water Properties (T:		2	6	9	15	26	43	66	82	130	185 grams
Date		30-Jul-07						γ (kN/m3)	9.81										
Sand		French Drain sand			A (m2)	0.01039		μ (Ns/m2)	1.0E-03	0	1	2	3	5	9	13	16	26	37 litres
Clay in suspension		0.5%	(kaolinite)						1.0E-04										
	Time after beginning flow with suspension of fines (min)																		
		Elevation	Water	Water	Water	Water	Water	Water	0	3	9	14	24	42	78	140	199	405	696
Pore volumes									0	0.5	1.7	2.7	4.5	7.5	12.5	19.1	23.9	37.8	53.6
Volume collected (mL)			130	140						125	139	130	120	107	85.5	61	52.5	40	35
Time taken to collect (s)			60	60						60	60	60	60	60	60	60	60	60	60
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15
	0	55		55						55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	43.9	42.9						43.8	44.1	44.8	45.7	47.4	49.1	51.5	52.1	52.6	52.8
Point 3 (cm)	4.5	7.2		41.3						41.9	42.2	43.8	43.5	44.8	45.9	47.6	48.6	47.6	48.1
Point 4 (cm)	8.5	11.2		40.4						41.0	41.3	41.9	42.6	44.0	45.4	47.1	48.0	47.6	47.2
Point 5 (cm)	12.5	15.2		37.5						37.8	37.9	38.0	38.3	38.5	38.5	38.1	37.8	36.2	35.5
Point 6 (cm)	16.5	19.2		33.65						33.8	33.8	34.0	34.0	34.2	33.8	33.4	33.2	32.2	31.6
Point 7 (cm)	20.5	23.2		30.85						31.0	31.0	31.1	31.2	31.3	31.3	31.2	31.0	30.2	29.6
Point 9 (cm)	23.5	26.2	28.05	28						27.9	28.0	27.9	27.9	27.8	27.7	27.5	27.4	27.3	27.3
	25	1.23	2.333333	28		2.33E-06				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L			Turb.	0	883	1100								
Calculations				1000	L/m^3					3.2	3.4	3.9	4.3	5.5	6.9	9.0	10.2	11.4	11.7
Q (m3/s)			2.17E-06	2.33E-06	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		2.08E-06	2.32E-06	2.17E-06	0.000002	1.78E-06	1.43E-06	1E-06	8.8E-07	6.7E-07	5.8E-07
i (Point 1-3)			14.63	0.53	0.00	0.00	0.00	0.00		0.63	0.63	0.32	0.73	0.87	1.07	1.32	1.17	1.67	1.57
i (Point 1-4)			6.27	0.36	0.00	0.00	0.00	0.00		0.40	0.40	0.41	0.45	0.49	0.53	0.63	0.59	0.72	0.80
i (Point 1-9)			0.72	0.68	0.00	0.00	0.00	0.00		0.72	0.73	0.77	0.81	0.89	0.98	1.09	1.12	1.15	1.16
i (Point 6-9)			-4.01	0.81	0.00	0.00	0.00	0.00		0.84	0.83	0.86	0.87	0.91	0.88	0.85	0.83	0.70	0.61
i (Point 3-4)			0.00	0.23	0.00	0.00	0.00	0.00		0.23	0.23	0.49	0.24	0.21	0.13	0.11	0.15	0.01	0.23
i (Point 4-5)			0.00	0.73	0.00	0.00	0.00	0.00		0.80	0.85	0.96	1.08	1.38	1.73	2.25	2.55	2.85	2.93
i (Point 5-6)			0.00	0.96	0.00	0.00	0.00	0.00		1.01	1.03	1.01	1.06	1.08	1.18	1.18	1.15	0.99	0.98
i (Point 6-7)			0.00	0.70	0.00	0.00	0.00	0.00		0.69	0.70	0.71	0.70	0.73	0.62	0.55	0.55	0.50	0.50
i (Point 7-9)			-9.35	0.95	0.00	0.00	0.00	0.00		1.03	1.00	1.07	1.10	1.15	1.22	1.25	1.20	0.97	0.77
K (m/s)																			
(Point 1-3)			1.4E-05	4.2E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		3.2E-04	3.5E-04	6.6E-04	2.6E-04	2.0E-04	1.3E-04	7.4E-05	7.2E-05	3.9E-05	3.6E-05
(Point 1-4)			3.3E-05	6.3E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		5.0E-04	5.6E-04	5.0E-04	4.3E-04	3.5E-04	2.6E-04	1.6E-04	1.4E-04	8.9E-05	7.0E-05
(Point 1-9)			2.9E-04	3.3E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	3.3E-04	2.8E-04	3.0E-04	2.7E-04	2.4E-04	1.9E-04	1.4E-04	9.0E-05	7.5E-05	5.6E-05	4.8E-05
(Point 6-9)			-5.2E-05	2.8E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		2.4E-04	2.7E-04	2.4E-04	2.2E-04	1.9E-04	1.6E-04	1.2E-04	1.0E-04	9.2E-05	9.1E-05
(Point 3-4)			#DIV/0!	1.0E-03	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		8.9E-04	9.9E-04	4.3E-04	8.1E-04	8.1E-04	1.1E-03	8.7E-04	5.6E-04	5.1E-03	2.5E-04
(Point 4-5)			#DIV/0!	3.1E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		2.5E-04	2.6E-04	2.2E-04	1.8E-04	1.2E-04	8.0E-05	4.4E-05	3.3E-05	2.3E-05	1.9E-05
(Point 5-6)			#DIV/0!	2.3E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		2.0E-04	2.2E-04	2.1E-04	1.8E-04	1.6E-04	1.2E-04	8.3E-05	7.3E-05	6.5E-05	5.8E-05
(Point 6-7)			#DIV/0!	3.2E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		2.9E-04	3.2E-04	2.9E-04	2.8E-04	2.4E-04	2.2E-04	1.8E-04	1.5E-04	1.3E-04	1.1E-04
(Point 7-9)			-2.2E-05	2.4E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		1.9E-04	2.2E-04	2.0E-04	1.8E-04	1.5E-04	1.1E-04	7.8E-05	7.0E-05	6.6E-05	7.3E-05
									3.3E-02	2.8E-02	3.0E-02	2.7E-02	2.4E-02	1.9E-02	1.4E-02	9.0E-03	7.5E-03	5.6E-03	4.8E-03
% of Ko (1-4)		Ko =					6.3E-04		1.00	0.80	0.89	0.80	0.68	0.55	0.41	0.25	0.23	0.14	0.11
% of Ko (1-9)		Ko =					3.3E-04		1.00	0.84	0.92	0.82	0.72	0.58	0.42	0.27	0.23	0.17	0.15
% of Ko (6-9)		Ko =					2.8E-04		1.00	0.86	0.97	0.87	0.79	0.68	0.56	0.41	0.37	0.33	0.33
% of Ko (1-3)		Ko =					4.2E-04		1.00	0.75	0.84	1.56	0.62	0.47	0.31	0.18	0.17	0.09	0.09
% of Ko (3-4)		Ko =					1.0E-03		1.00	0.89	0.99	0.43	0.81	0.81	1.10	0.87	0.56	5.14	0.25
% of Ko (4-5)		Ko =					3.1E-04		1.00	0.81	0.85	0.70	0.58	0.40	0.26	0.14	0.11	0.07	0.06
% of Ko (5-6)		Ko =					2.3E-04		1.00	0.85	0.93	0.88	0.78	0.68	0.50	0.36	0.31	0.28	0.25
% of Ko (6-7)		Ko =					3.2E-04		1.00	0.91	0.99	0.91	0.86	0.74	0.68	0.55	0.48	0.40	0.35
% of Ko (7-9)		Ko =					2.4E-04		1.00	0.82	0.94	0.83	0.74	0.63	0.48	0.33	0.30	0.28	0.31
		Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	k placement				Tare	14.38			14.40	14.27	13.30	14.57
		AB-1	91.83	680.85	659.36	21.49	3.6%	5				Volume	9.90			10.00	9.90	10.00	10.00
		AB-2	96.94	673.08	653.64	19.44	3.4%	6				Mass After	14.40			14.43	14.31	13.35	14.61
		AB-3	85.86	771.59	744.09	27.50	4.0%	3				g solids	0.02			0.03	0.04	0.05	0.04
		AB-4	87.01	700.94	674.29	26.65	4.3%	1				g clay	0.02			0.03	0.04	0.05	0.04
		AB-5	85.05	695.71	669.36	26.35	4.3%	3				clay (g/L)	2.02			3.00	4.04	5.00	4.00
		AB-6	83.76	821.68	788.40	33.28	4.5%	2											
			530.45	4343.85	4189.14	154.71	4.1%		0.00	0.00	0.00	0.00	2.53	6.65	13.65	27.28	40.81	88.44	132.09
					Post-test total mass of fines	155 g		0.037	Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).										
					Mass of fines injected	185 g													
						16.1%													

Constant HeadTest min ml s

Test AF 2nd setup ml s min 38000

Date 29-Aug-07 Water Properties (T= 20C) 40280

Sand French Drain sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.5% kaolinite 5 g/L Readings 3, 5, 7 assumed

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine				0	7	15	23	29	40	49	59	69	78	87	98	131	158	188
Pore volumes									0	0.8	1.8	2.6	3.3	4.4	5.2	6.1	6.9	7.7	8.3	9.1	11.2	12.6	14.0
Volume collected (mL)			92	88	87					82	78	73	71	67.5	63	59	56	53	51	48	39	34	29
Time taken to collect (s)			60	60	60					60	60	60	60	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)			15	15	15					15	15	15	15	15	15	15	15	15	15	15	15	15	15
		Ohmeter Readings			55					55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	1.5	47.6	48.1	48.2					48.8	49.2	49.5	49.8	50.3	50.6	51.0	51.2	51.5	51.7	52.0	52.7	53.1	53.4
Point 3 (cm)	4.5	4.5			47					47.0	47.3	47.7	47.9	48.1	48.3	48.5	48.6	48.7	48.8	49.0	50.2	50.7	51.0
Point 4 (cm)	8.5	8.5	41.2	41.85	42.1					42.2	42.2	42.2	42.2	42.1	42.0	41.9	41.8	41.6	41.6	41.4	41.0	40.4	40.1
Point 5 (cm)	12.5	12.5			36.6					36.6	36.5	36.4	36.3	36.0	35.9	35.6	35.5	35.2	35.1	34.8	34.2	33.9	33.5
Point 6 (cm)	16.5	16.5	32.85	33	33.2					33.1	33.0	32.9	32.8	32.7	32.6	32.4	32.3	32.1	32.0	31.9	31.5	31.3	31.0
Point 7 (cm)	20.5	20.5			30.9					30.9	30.9	30.9	30.9	30.8	30.7	30.7	30.6	30.5	30.4	30.3	30.1	30.0	29.8
Point 9 (cm)	23.5	23.5	28.8	28.8	28.8					28.8	28.8	28.7	28.7	28.6	28.6	28.5	28.5	28.5	28.5	28.4	28.3	28.2	28.2
	25			1.466667	28	1.47E-06				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L			Turb.	0	185.0	303.0	372	408	476	500	522	560	573	587	584	658	820	672
Calculations				1000	L/m^3																		
Q (m3/s)			1.53E-06	1.47E-06	1.45E-06					1.367E-06	0.0000013	1.217E-06	1.183E-06	1.125E-06	1.05E-06	9.83333E-07	9.33333E-07	8.83333E-07	0.00000085	0.0000008	0.00000065	5.66667E-07	4.83333E-07
i (Point 1-3)			15.87	16.03	0.40					0.60	0.63	0.62	0.63	0.73	0.77	0.83	0.87	0.93	0.97	1.00	0.83	0.80	0.80
i (Point 1-4)			0.91	0.89	0.87					0.94	1.00	1.04	1.09	1.17	1.23	1.30	1.34	1.41	1.44	1.51	1.67	1.81	1.90
i (Point 1-9)			0.85	0.88	0.88					0.91	0.93	0.95	0.96	0.99	1.00	1.02	1.03	1.05	1.05	1.07	1.11	1.13	1.15
i (Point 6-9)			0.58	0.60	0.63					0.61	0.60	0.60	0.59	0.59	0.57	0.56	0.54	0.51	0.50	0.50	0.46	0.44	0.40
i (Point 3-4)			-10.30	-10.46	1.23					1.20	1.28	1.36	1.43	1.50	1.58	1.65	1.70	1.78	1.80	1.90	2.30	2.58	2.73
i (Point 4-5)			10.30	10.46	1.38					1.40	1.43	1.45	1.49	1.53	1.53	1.58	1.58	1.60	1.63	1.65	1.70	1.63	1.65
i (Point 5-6)			-8.21	-8.25	0.85					0.89	0.88	0.88	0.86	0.82	0.82	0.80	0.80	0.78	0.78	0.73	0.68	0.66	0.63
i (Point 6-7)			8.21	8.25	0.58					0.54	0.53	0.50	0.48	0.48	0.48	0.43	0.42	0.40	0.40	0.40	0.35	0.31	0.30
i (Point 7-9)			-9.60	-9.60	0.70					0.70	0.70	0.73	0.73	0.73	0.70	0.73	0.70	0.67	0.63	0.63	0.60	0.60	0.53
				V =	0.000140 m/s		0.000140																
				V*e =	0.000397 m/s																		
K (m/s)																							
(Point 1-3)			9.3E-06	8.8E-06	3.5E-04					2.2E-04	2.0E-04	1.9E-04	1.8E-04	1.5E-04	1.3E-04	1.1E-04	1.0E-04	9.1E-05	8.5E-05	7.7E-05	7.5E-05	6.8E-05	5.8E-05
(Point 1-4)			1.6E-04	1.6E-04	1.6E-04					1.4E-04	1.3E-04	1.1E-04	1.0E-04	9.2E-05	8.2E-05	7.3E-05	6.7E-05	6.0E-05	5.7E-05	5.1E-05	3.7E-05	3.0E-05	2.4E-05
(Point 1-9)			1.7E-04	1.6E-04	1.6E-04					1.4E-04	1.3E-04	1.2E-04	1.2E-04	1.1E-04	1.0E-04	9.3E-05	8.7E-05	8.1E-05	7.8E-05	7.2E-05	5.6E-05	4.8E-05	4.1E-05
(Point 6-9)			2.6E-04	2.4E-04	2.2E-04					2.2E-04	2.1E-04	2.0E-04	1.9E-04	1.8E-04	1.8E-04	1.7E-04	1.7E-04	1.7E-04	1.6E-04	1.5E-04	1.4E-04	1.3E-04	1.2E-04
(Point 3-4)			-1.4E-05	-1.3E-05	1.1E-04					1.1E-04	9.8E-05	8.6E-05	8.0E-05	7.2E-05	6.4E-05	5.7E-05	5.3E-05	4.8E-05	4.5E-05	4.1E-05	2.7E-05	2.1E-05	1.7E-05
(Point 4-5)			1.4E-05	1.3E-05	1.0E-04					9.4E-05	8.8E-05	8.1E-05	7.7E-05	7.1E-05	6.6E-05	6.0E-05	5.7E-05	5.3E-05	5.0E-05	4.7E-05	3.7E-05	3.4E-05	2.8E-05
(Point 5-6)			-1.8E-05	-1.7E-05	1.6E-04					1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.2E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	9.3E-05	8.2E-05	7.4E-05
(Point 6-7)			1.8E-05	1.7E-05	2.4E-04					2.4E-04	2.4E-04	2.3E-04	2.4E-04	2.3E-04	2.1E-04	2.2E-04	2.1E-04	2.1E-04	2.0E-04	1.9E-04	1.8E-04	1.7E-04	1.6E-04
(Point 7-9)			-1.5E-05	-1.5E-05	2.0E-04					1.9E-04	1.8E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.0E-04	9.1E-05	8.7E-05

% of Ko (1-4)	Ko =	1.6E-04	1.00	0.87	0.78	0.70	0.66	0.58	0.51	0.45	0.42	0.38	0.35	0.32	0.23	0.19	0.15
% of Ko (1-9)	Ko =	1.6E-04	1.00	0.91	0.85	0.78	0.75	0.69	0.64	0.58	0.55	0.51	0.49	0.45	0.36	0.30	0.26
% of Ko (6-9)	Ko =	2.2E-04	1.00	0.98	0.94	0.88	0.88	0.83	0.80	0.77	0.75	0.74	0.74	0.69	0.62	0.56	0.52
% of Ko (1-3)	Ko =	3.5E-04	1.00	0.63	0.57	0.54	0.52	0.42	0.38	0.33	0.30	0.26	0.24	0.22	0.22	0.20	0.17
% of Ko (3-4)	Ko =	1.1E-04	1.00	0.96	0.86	0.75	0.70	0.63	0.56	0.50	0.46	0.42	0.40	0.36	0.24	0.19	0.15
% of Ko (4-5)	Ko =	1.0E-04	1.00	0.93	0.87	0.80	0.75	0.70	0.65	0.59	0.56	0.52	0.50	0.46	0.36	0.33	0.28
% of Ko (5-6)	Ko =	1.6E-04	1.00	0.90	0.87	0.82	0.80	0.80	0.75	0.72	0.68	0.67	0.64	0.65	0.56	0.50	0.45
% of Ko (6-7)	Ko =	2.4E-04	1.00	1.01	0.98	0.96	0.99	0.94	0.88	0.92	0.87	0.88	0.84	0.79	0.74	0.72	0.64
% of Ko (7-9)	Ko =	2.0E-04	1.00	0.94	0.90	0.80	0.78	0.74	0.72	0.65	0.64	0.64	0.65	0.61	0.52	0.46	0.44

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines		
AF-1	89.31	782.94	758.37	24.57	3.5%	5	4.3%
AF-2	95.80	818.27	794.4	23.87	3.3%	6	3.9%
AF-3	102.05	725.30	701.02	24.28	3.9%	3	4.0%
AF-4	83.58	747.47	715.79	31.68	4.8%	2	5.2%
AF-5	88.41	673.74	646.45	27.29	4.7%	1	4.7%
AF-6	87.52	786.77	750.15	36.62	5.2%	4	5.8%
	546.67	4534.49	4366.18	168.31	4.2%		
			Post-test total mass of fines	168 g		0.042	
			Mass of fines injected	141 g			

0.042 Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

29A	
Tare	14.48
Volume	19.10
Mass After	15.00
g solids	0.52
g salt	0.56
g clay	-0.04
clay (g/L)	-1.99

1.06							141 g
10.4	11.2	12.2	12.7	13.7	16.3	26.4	28.2 L
215	246	292	315	368	525	1316	1496
15.1	16.3	17.8	18.4	19.9	23.6	38.3	41.0
27	24	21	19	18	15	10.5	10.5
60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15
55	55	55	55	55	55	55	55
53.5	53.7	54.0	54.0	54.0	54.0	54.0	53.9
51.4	51.8	52.4	52.5	52.5	52.8	52.7	52.3
40.5	40.4	40.4	40.3	40.4	40.9	39.6	38.2
33.6	33.3	33.1	33.0	32.9	34.2	38.9	38.1
31.0	30.8	30.7	30.7	30.6	30.3	31.5	31.8
29.7	29.6	29.5	29.5	29.5	29.2	32.0	30.6
28.2	28.1	28.1	28.0	28.0	28.0	28.6	29.1
28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
707	675	561	486	555	542.0	1100	

0.00000045	0.0000004	0.00000035	3.16667E-07	0.0000003	0.00000025	0.000000175	0.000000175
0.70	0.63	0.53	0.50	0.50	0.40	0.43	0.53
1.86	1.90	1.94	1.96	1.94	1.87	2.06	2.24
1.15	1.16	1.18	1.18	1.18	1.18	1.15	1.13
0.39	0.39	0.37	0.39	0.37	0.32	0.41	0.39
2.73	2.85	3.00	3.05	3.03	2.98	3.28	3.53
1.73	1.78	1.83	1.83	1.88	1.69	0.18	0.03
0.66	0.62	0.60	0.58	0.57	0.98	1.85	1.58
0.31	0.30	0.30	0.30	0.28	0.26	-0.13	0.30
0.50	0.50	0.47	0.50	0.50	0.40	1.13	0.50

6.2E-05	6.1E-05	6.3E-05	6.1E-05	5.8E-05	6.0E-05	3.9E-05	3.2E-05
2.3E-05	2.0E-05	1.7E-05	1.6E-05	1.5E-05	1.3E-05	8.2E-06	7.5E-06
3.8E-05	3.3E-05	2.9E-05	2.6E-05	2.4E-05	2.0E-05	1.5E-05	1.5E-05
1.1E-04	1.0E-04	9.1E-05	7.9E-05	7.8E-05	7.5E-05	4.1E-05	4.4E-05
1.6E-05	1.4E-05	1.1E-05	1.0E-05	9.5E-06	8.1E-06	5.1E-06	4.8E-06
2.5E-05	2.2E-05	1.8E-05	1.7E-05	1.5E-05	1.4E-05	9.6E-05	6.7E-04
6.5E-05	6.2E-05	5.6E-05	5.3E-05	5.0E-05	2.5E-05	9.1E-06	1.1E-05
1.4E-04	1.3E-04	1.1E-04	1.0E-04	1.1E-04	9.2E-05	-1.3E-04	5.6E-05
8.7E-05	7.7E-05	7.2E-05	6.1E-05	5.8E-05	6.0E-05	1.5E-05	3.4E-05
0.15	0.13	0.11	0.10	0.09	0.08	0.05	0.05
0.24	0.21	0.18	0.16	0.15	0.13	0.09	0.09
0.50	0.45	0.41	0.36	0.35	0.34	0.18	0.20
0.18	0.17	0.18	0.17	0.17	0.17	0.11	0.09
0.14	0.12	0.10	0.09	0.08	0.07	0.05	0.04
0.25	0.21	0.18	0.16	0.15	0.14	0.95	6.64
0.40	0.38	0.34	0.32	0.31	0.15	0.06	0.07
0.57	0.53	0.46	0.42	0.43	0.38	-0.56	0.23
0.43	0.39	0.36	0.31	0.29	0.30	0.07	0.17

47A	41A	72A
14.51	14.57	14.06
19.10	19.5	20
15.01	15.12	14.70
0.50	0.55	0.64
0.56	0.57	0.58
-0.06	-0.02	0.06
-3.04	-1.01	2.78

Constant HeadTest

Test AH

Date Aug 30, 2007

Sand French Drain sand A (m2) 0.01039

Clay in suspension 0.3% Kaolinite 2.5 g/L

min ml s

ml s min

Water Properties (T= 20C)

γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

84

33.7

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine					0	4	14	23	31	39	48	55	65	85	116	339	1051	1100	1185	1261	1342	1432
Pore volumes								0	0.5	1.8	2.8	3.7	4.5	5.5	6.1	7.1	9.0	11.6	24.6	43.8	44.6	45.9	46.9	48.0	48.9
Volume collected (mL)		105.5	100						92	82	76	74	71	69	67	65	62	56	24.5	12.5	11.5	9.4	9.2	8.1	6.9
Time taken to collect (s)		60	60						60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)		15	15						15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																									
Point 1 (cm)	1.5	45.5	45.8						45.8	46.0	46.4	46.5	46.7	46.9	47.1	47.3	47.6	48.2	45.9	49.8	49.7	49.1	48.8	48.3	48.0
Point 2 (cm)	3																								
Point 3 (cm)	4.5								43.5	43.5	43.8	43.9	44.0	44.2	44.3	44.5	44.9	45.4	43.6	47.1	47.2	45.9	44.2	43.6	44.3
Point 4 (cm)	8.5	39.75	40.1						39.7	39.7	39.8	39.9	40.0	40.0	40.0	40.0	40.0	40.3	39.3	39.3	39.1	38.3	38.1	37.5	37.2
Point 5 (cm)	12.5								36.8	36.8	36.9	36.9	36.9	36.9	36.9	37.0	37.0	37.1	36.5	36.8	36.7	36.2	36.0	35.6	35.4
Point 6 (cm)	16.5	32.45	32.45						32.1	32.0	32.0	32.0	31.9	31.9	31.8	31.8	31.7	31.6	30.7	31.9	31.9	31.7	31.7	31.6	31.6
Point 7 (cm)	20.5								30.3	30.2	30.2	30.2	30.3	30.3	30.2	30.2	30.2	30.1	29.5	30.3	30.3	30.3	30.3	30.3	30.3
Point 8 (cm)	22																								
Point 9 (cm)	23.5	30	30						29.8	29.7	29.7	29.7	29.7	29.8	29.7	29.7	29.7	29.7	29.3	30.0	30.0	30.0	30.0	30.0	30.0
			1.666667		1.67E-06																				
			1000	mL/L			Turb.	0	141	111	167	148	165	180	188	214	242	267	268	754	678	641	616	540	486
Calculations			1000	L/m^3																					
Q (m3/s)		1.76E-06	1.67E-06						1.53E-06	1.37E-06	1.27E-06	1.23E-06	1.18E-06	1.15E-06	1.12E-06	1.08E-06	1.03E-06	9.33E-07	4.08E-07	2.08E-07	1.92E-07	1.57E-07	1.53E-07	1.35E-07	1.15E-07
i (Point 1-3)		15.17	15.27						0.75	0.83	0.87	0.87	0.90	0.90	0.93	0.93	0.92	0.93	0.77	0.90	0.85	1.07	1.53	1.57	1.23
i (Point 1-4)		0.82	0.81						0.87	0.90	0.94	0.94	0.96	0.99	1.01	1.04	1.09	1.13	0.95	1.51	1.51	1.54	1.53	1.54	1.54
i (Point 1-9)		0.70	0.72						0.73	0.74	0.76	0.76	0.77	0.78	0.79	0.80	0.81	0.84	0.75	0.90	0.90	0.87	0.85	0.83	0.82
i (Point 6-9)		0.35	0.35						0.33	0.33	0.33	0.33	0.31	0.30	0.30	0.29	0.29	0.27	0.19	0.27	0.27	0.24	0.24	0.23	0.23
i (Point 4-6)		0.91	0.96						0.94	0.96	0.98	0.99	1.01	1.01	1.03	1.03	1.04	1.09	1.08	0.92	0.90	0.83	0.80	0.74	0.70
i (Point 4-7)		3.31	3.34						0.78	0.79	0.80	0.81	0.81	0.81	0.82	0.82	0.82	0.85	0.81	0.75	0.73	0.67	0.65	0.60	0.58
K (m/s)																									
(Point 1-3)		1.1E-05	1.1E-05						2.0E-04	1.6E-04	1.4E-04	1.4E-04	1.3E-04	1.2E-04	1.2E-04	1.1E-04	1.1E-04	9.6E-05	5.1E-05	2.2E-05	2.2E-05	1.4E-05	9.6E-06	8.3E-06	9.0E-06
(Point 1-4)		2.06E-04	1.97E-04						1.7E-04	1.5E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	1.1E-04	1.0E-04	9.2E-05	8.0E-05	4.1E-05	1.3E-05	1.2E-05	9.8E-06	9.7E-06	8.4E-06	7.2E-06
(Point 1-9)		2.40E-04	2.23E-04						2.0E-04	1.8E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04	1.4E-04	1.3E-04	1.2E-04	1.1E-04	5.2E-05	2.2E-05	2.1E-05	1.7E-05	1.7E-05	1.6E-05	1.4E-05
(Point 6-9)		4.84E-04	4.58E-04						4.5E-04	4.0E-04	3.7E-04	3.6E-04	3.6E-04	3.7E-04	3.6E-04	3.6E-04	3.5E-04	3.3E-04	2.0E-04	7.4E-05	6.8E-05	6.2E-05	6.1E-05	5.7E-05	4.8E-05
(Point 4-6)		1.9E-04	1.7E-04						1.6E-04	1.4E-04	1.3E-04	1.2E-04	1.1E-04	1.1E-04	1.0E-04	1.0E-04	9.6E-05	8.3E-05	3.7E-05	2.2E-05	2.1E-05	1.8E-05	1.8E-05	1.8E-05	1.6E-05
(Point 4-7)		5.1E-05	4.8E-05						1.9E-04	1.7E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	4.8E-05	2.7E-05	2.5E-05	2.3E-05	2.3E-05	2.2E-05	1.9E-05
% of Ko (1-4)	Ko =					2.0E-04		1.00	0.86	0.74	0.66	0.64	0.60	0.57	0.54	0.51	0.47	0.40	0.21	0.07	0.06	0.05	0.05	0.04	0.04
% of Ko (1-9)	Ko =					2.2E-04		1.00	0.91	0.79	0.72	0.70	0.66	0.64	0.61	0.58	0.55	0.48	0.23	0.10	0.09	0.08	0.08	0.07	0.06
% of Ko (6-9)	Ko =					4.6E-04		1.00	0.98	0.87	0.81	0.79	0.79	0.81	0.78	0.78	0.76	0.72	0.44	0.16	0.15	0.14	0.13	0.12	0.11
% of Ko (4-6)	Ko =					1.7E-04		1.00	0.93	0.81	0.75	0.72	0.67	0.65	0.63	0.60	0.57	0.49	0.22	0.13	0.12	0.11	0.11	0.11	0.09
										46A			36A			Z4			6A	57A				3A	47A
	Sample	Tare	Pre-wash	Post-wash	Fines	% Fines			Tare	14.24			14.53			14.33			14.29	14.5				14.63	14.48
	AG-1	88.68	753.52	721.79	31.73	4.8%	3		Volume	19.80			19.50			19.3			19.1	19.6				16.5	14.7
	AG-2	87.03	611.47	588.93	22.54	4.3%			Mass After	14.83			15.10			15.06			14.87	15.13				15.10	14.89
	AG-3	92.53	745.90	718.66	27.24	4.2%	2		g solids	0.59			0.57			0.73			0.58	0.63				0.47	0.41
	AG-4	83.75	763.79	739.32	24.47	3.6%			g salt	0.58			0.57			0.56			0.56	0.57				0.48	0.43
	AG-5	96.94	737.93	718.59	19.34	3.0%			g clay	0.01			0.00			0.17			0.02	0.06				-0.01	-0.02
	AG-6	91.84	846.49	821.40	25.09	3.3%	1		clay (g/L)	0.58			0.01			8.60			1.15	2.92				-0.74	-1.33
		540.77	4459.10	4308.69	150.41	3.8%																			
				Post-test total mass of fines	150 g		3.5E-02 Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).																		
				Mass of fines injected	84 g																				

Constant HeadTest min ml s

Test AC (1st setup but 2nd column) ml s min

Date 22-Aug-07 Water Properties (T= 20C)

Sand French Drain sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.1% (kaolinite) 1 g/L

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2	7	16	24	30	48	82	195	298	567	792	1064	1187
Pore volumes									0	0.2	0.8	1.8	2.6	3.3	5.2	8.6	19.5	28.8	48.4	60.9	74.0	79.6
Volume collected (mL)			121	97	81.5	80	81	79.5		79	77	75	73	72.5	70.5	68	65	59	41.5	35	31.5	31
Time taken to collect (s)			60	60	60	60	60	60		60	60	60	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15
	0	hometer Readings						55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	44.1	45.7	47.45	47.55	47.8	47.95		48.0	48.1	48.1	48.1	48.1	48.1	48.3	48.6	48.6	49.0	45.8	44.8	44.2
Point 3 (cm)	4.5	7.2	41.2	41.8	43.5	43.75	44.2	44.7		44.7	44.6	44.6	44.6	44.6	44.6	44.8	45.7	46.3	46.4	44.2	43.2	42.7
Point 4 (cm)	8.5	11.2	36.8	36.8	37.8	38	38.4	38.7		38.7	38.7	38.7	38.7	38.7	38.5	38.7	39.5	40.2	41.1	40.3	39.1	38.6
Point 5 (cm)	12.5	15.2	35.1	35.2	35.9	36.05	36.4	36.7		36.6	36.6	36.6	36.6	36.5	36.5	36.7	37.3	38.3	39.2	38.8	37.6	37.1
Point 6 (cm)	16.5	19.2	31.3	31	32.2	32.3	32.4	32.6		32.7	32.7	32.7	32.6	32.4	32.3	32.3	32.9	33.9	33.6	33.9	34.0	33.8
Point 7 (cm)	20.5	23.2	29.2	29	29	29.1	29	29		29.0	29.1	29.0	29.0	29.0	28.9	28.8	28.8	28.8	28.7	28.7	28.5	28.5
Point 9 (cm)	23.5	26.2	28.65	28.4	28.3	28.4	28.3	28.3		28.3	28.3	28.3	28.3	28.3	28.3	28.2	28.3	28.2	28.2	28.1	27.9	27.8
	25			1.616667		1.62E-06		28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
				1000	mL/L			Turb.	0	6.7	7.7	11	14	19	20	31	71	143	210	376	469	547
Calculations				1000	L/m^3																	
Q (m3/s)			2.02E-06	1.62E-06	1.36E-06	1.33E-06	1.35E-06	1.33E-06		1.317E-06	1.283E-06	1.25E-06	1.217E-06	1.208E-06	1.175E-06	1.1333E-06	1.0833E-06	9.8333E-07	6.9167E-07	5.83E-07	5.25E-07	5.17E-07
i (Point 1-3)			0.97	1.30	1.32	1.27	1.20	1.08		1.12	1.17	1.17	1.17	1.17	1.17	1.15	0.97	0.77	0.87	0.53	0.52	0.50
i (Point 1-4)			1.04	1.27	1.38	1.36	1.34	1.32		1.33	1.34	1.34	1.34	1.35	1.37	1.36	1.30	1.20	1.13	0.79	0.81	0.80
i (Point 1-9)			0.70	0.79	0.87	0.87	0.89	0.89		0.90	0.90	0.90	0.90	0.90	0.90	0.91	0.93	0.93	0.95	0.80	0.77	0.75
i (Point 6-9)			0.38	0.37	0.56	0.56	0.59	0.61		0.63	0.63	0.63	0.61	0.59	0.58	0.59	0.66	0.82	0.78	0.83	0.86	0.86
i (Point 3-4)			1.10	1.25	1.43	1.44	1.45	1.50		1.49	1.46	1.48	1.48	1.49	1.53	1.53	1.55	1.53	1.33	0.98	1.03	1.03
i (Point 4-5)			0.42	0.40	0.48	0.49	0.50	0.50		0.53	0.53	0.54	0.53	0.54	0.50	0.50	0.55	0.48	0.48	0.38	0.39	0.38
i (Point 5-6)			0.95	1.05	0.92	0.94	1.00	1.03		0.98	0.98	0.96	1.00	1.03	1.05	1.10	1.10	1.10	1.40	1.23	0.90	0.83
i (Point 6-7)			0.53	0.50	0.80	0.80	0.85	0.90		0.93	0.91	0.93	0.90	0.85	0.86	0.89	1.04	1.28	1.23	1.30	1.36	1.33
i (Point 7-9)			0.18	0.20	0.23	0.23	0.23	0.23		0.23	0.25	0.23	0.23	0.23	0.20	0.18	0.17	0.22	0.18	0.20	0.20	0.23
K (m/s)																						
(Point 1-3)			2.0E-04	1.2E-04	9.9E-05	1.0E-04	1.1E-04	1.2E-04		1.1E-04	1.1E-04	1.0E-04	1.0E-04	1.0E-04	9.7E-05	9.5E-05	1.1E-04	1.2E-04	7.7E-05	1.1E-04	9.8E-05	9.9E-05
(Point 1-4)			1.9E-04	1.2E-04	9.5E-05	9.4E-05	9.7E-05	9.7E-05		9.5E-05	9.2E-05	9.0E-05	8.7E-05	8.6E-05	8.2E-05	8.0E-05	8.0E-05	7.9E-05	5.9E-05	7.1E-05	6.3E-05	6.2E-05
(Point 1-9)			2.8E-04	2.0E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04		1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	1.0E-04	7.0E-05	7.0E-05	6.6E-05	6.7E-05
(Point 6-9)			5.1E-04	4.2E-04	2.3E-04	2.3E-04	2.2E-04	2.1E-04		2.0E-04	2.0E-04	1.9E-04	1.9E-04	2.0E-04	2.0E-04	1.9E-04	1.6E-04	1.2E-04	8.6E-05	6.8E-05	5.8E-05	5.8E-05
(Point 3-4)			1.8E-04	1.2E-04	9.2E-05	8.9E-05	9.0E-05	8.5E-05		8.5E-05	8.4E-05	8.2E-05	7.9E-05	7.8E-05	7.4E-05	7.2E-05	6.7E-05	6.2E-05	5.0E-05	5.8E-05	4.9E-05	4.9E-05
(Point 4-5)			4.6E-04	3.9E-04	2.8E-04	2.6E-04	2.6E-04	2.6E-04		2.4E-04	2.4E-04	2.2E-04	2.2E-04	2.2E-04	2.3E-04	2.2E-04	1.9E-04	2.0E-04	1.4E-04	1.5E-04	1.3E-04	1.3E-04
(Point 5-6)			2.0E-04	1.5E-04	1.4E-04	1.4E-04	1.3E-04	1.2E-04		1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	1.1E-04	9.9E-05	9.5E-05	8.6E-05	4.8E-05	4.6E-05	5.6E-05	6.0E-05
(Point 6-7)			3.7E-04	3.1E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04		1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.4E-04	1.3E-04	1.2E-04	1.0E-04	7.4E-05	5.4E-05	4.3E-05	3.7E-05	3.8E-05
(Point 7-9)			1.1E-03	7.8E-04	5.6E-04	5.5E-04	5.6E-04	5.5E-04		5.4E-04	4.9E-04	5.2E-04	5.0E-04	5.0E-04	5.7E-04	6.0E-04	6.3E-04	4.4E-04	3.6E-04	2.8E-04	2.5E-04	2.1E-04
% of Ko (1-4)		Ko =					9.7E-05		1.00	0.99	0.96	0.93	0.90	0.89	0.85	0.83	0.83	0.82	0.61	0.74	0.65	0.64
% of Ko (1-9)		Ko =					1.4E-04		1.00	0.99	0.96	0.94	0.91	0.91	0.88	0.84	0.79	0.71	0.49	0.49	0.46	0.47
% of Ko (6-9)		Ko =					2.1E-04		1.00	0.97	0.95	0.92	0.92	0.96	0.94	0.90	0.76	0.55	0.41	0.33	0.28	0.28
% of Ko (1-3)		Ko =					1.2E-04		1.00	0.96	0.90	0.88	0.85	0.85	0.82	0.81	0.92	1.05	0.65	0.89	0.83	0.84
% of Ko (3-4)		Ko =					8.5E-05		1.00	1.00	0.99	0.96	0.93	0.92	0.87	0.84	0.79	0.73	0.59	0.68	0.58	0.57
% of Ko (4-5)		Ko =					2.6E-04		1.00	0.95	0.92	0.88	0.87	0.85	0.89	0.86	0.74	0.78	0.55	0.59	0.51	0.52
% of Ko (5-6)		Ko =					1.2E-04		1.00	1.04	1.02	1.00	0.94	0.91	0.87	0.80	0.76	0.69	0.38	0.37	0.45	0.48
% of Ko (6-7)		Ko =					1.4E-04		1.00	0.97	0.96	0.92	0.92	0.97	0.93	0.87	0.71	0.52	0.38	0.30	0.26	0.26
% of Ko (7-9)		Ko =					5.5E-04		1.00	0.99	0.90	0.94	0.92	0.91	1.03	1.09	1.14	0.80	0.66	0.51	0.46	0.39

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
AC-1	82.26	685.07	666.35	18.72	3.1%	1
AC-2	78.56	635.92	619.5	16.42	2.9%	2
AC-3	86.73	733.18	711.84	21.34	3.3%	5
AC-4	108.28	757.51	736.01	21.50	3.3%	6
AC-5	88.66	712.44	687.56	24.88	4.0%	4
AC-6	84.42	910.78	867.34	43.44	5.3%	3
	528.91	4434.90	4288.60	146.30	3.7%	
		Post-test total mass of fines		146	g	0.03411
		Mass of fines injected		84	g	
				25.2%		

Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

Tare	13.29	13.16	14.08
Volume	9.25	10	9.8
Mass After	13.57	13.47	14.36
g solids	0.28	0.31	0.28
g salt	0.27	0.29	0.29
g clay	0.01	0.02	-0.01
clay (g/L)	1.05	1.78	-0.65

38000	1.06									84.5 g
40280										
	60.6	62.9	64.7	67.3	71.9	79.8	81.0	81.9	83.1	84.5 L

1269	1380	1473	1560	1690	1928	2455	2564	2643	2771	2942
83.3	88.0	91.4	93.9	97.7	104.4	115.8	117.6	118.9	120.6	122.7
31	28	21	20	20	18.5	11.5	11	10.5	8.5	8
60	60	60	60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15	15	15	15
55	55	55	55	55	55	55	55	55	55	55
43.5	43.3	43.0	43.0	42.6	41.2	37.5	37.2	37.0	36.7	36.6
41.9	41.7	41.7	41.7	41.2	39.4	35.5	35.4	35.0	34.8	34.4
37.9	37.5	37.4	37.3	36.8	35.3	33.2	33.2	32.8	32.5	32.4
36.4	36.2	36.4	36.4	36.0	34.4	32.6	32.6	32.3	32.1	31.9
33.5	33.5	33.8	33.9	33.5	32.5	31.1	31.2	31.0	30.8	30.8
28.7	28.8	28.7	28.7	28.6	28.6	28.2	28.2	28.2	28.1	28.2
27.8	27.8	27.7	27.7	27.7	27.7	27.6	27.6	27.5	27.5	27.5
28	28	28	28	28	28	28	28	28	28	28
605	578	502	555	610	745	446.0	653	371	434	

5.17E-07	4.67E-07	3.5E-07	3.33E-07	3.33E-07	3.08E-07	1.92E-07	1.83E-07	1.75E-07	1.42E-07	1.33E-07	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
0.53	0.53	0.43	0.42	0.47	0.60	0.65	0.62	0.67	0.63	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.80	0.83	0.80	0.81	0.83	0.84	0.61	0.57	0.60	0.60	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.71	0.70	0.70	0.69	0.68	0.61	0.45	0.44	0.43	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.81	0.81	0.86	0.89	0.84	0.69	0.51	0.51	0.50	0.47	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	1.05	1.08	1.10	1.10	1.03	0.57	0.54	0.55	0.57	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.38	0.34	0.25	0.23	0.20	0.23	0.15	0.15	0.13	0.10	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.73	0.66	0.66	0.63	0.63	0.48	0.38	0.36	0.32	0.33	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.21	1.18	1.26	1.30	1.23	0.98	0.73	0.74	0.71	0.68	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.28	0.33	0.33	0.33	0.32	0.30	0.22	0.22	0.22	0.20	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

9.3E-05	8.4E-05	7.8E-05	7.7E-05	6.9E-05	4.9E-05	2.8E-05	2.9E-05	2.5E-05	2.2E-05	1.8E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
6.2E-05	5.4E-05	4.2E-05	4.0E-05	3.9E-05	3.5E-05	3.0E-05	3.1E-05	2.8E-05	2.3E-05	2.1E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
7.0E-05	6.4E-05	4.8E-05	4.6E-05	4.7E-05	4.8E-05	4.1E-05	4.0E-05	3.9E-05	3.3E-05	3.1E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
6.1E-05	5.5E-05	3.9E-05	3.6E-05	3.8E-05	4.3E-05	3.6E-05	3.4E-05	3.4E-05	2.9E-05	2.7E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
5.0E-05	4.3E-05	3.1E-05	2.9E-05	2.9E-05	2.9E-05	3.2E-05	3.3E-05	3.1E-05	2.4E-05	2.6E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
1.3E-04	1.3E-04	1.3E-04	1.4E-04	1.6E-04	1.3E-04	1.2E-04	1.2E-04	1.3E-04	1.4E-04	1.0E-04	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
6.9E-05	6.8E-05	5.1E-05	5.1E-05	5.1E-05	6.2E-05	4.9E-05	4.9E-05	5.2E-05	4.2E-05	4.7E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
4.1E-05	3.8E-05	2.7E-05	2.5E-05	2.6E-05	3.0E-05	2.5E-05	2.4E-05	2.4E-05	2.0E-05	2.0E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
1.8E-04	1.3E-04	1.0E-04	9.6E-05	1.0E-04	9.9E-05	8.5E-05	8.1E-05	7.8E-05	6.8E-05	5.1E-05	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

0.64	0.56	0.44	0.41	0.40	0.36	0.31	0.32	0.29	0.24	0.22
0.49	0.45	0.34	0.32	0.33	0.34	0.29	0.28	0.27	0.23	0.22
0.29	0.27	0.19	0.17	0.18	0.21	0.18	0.17	0.16	0.14	0.13
0.79	0.72	0.66	0.65	0.58	0.42	0.24	0.24	0.21	0.18	0.15
0.58	0.50	0.37	0.34	0.34	0.34	0.38	0.39	0.36	0.28	0.30
0.52	0.52	0.53	0.56	0.63	0.52	0.48	0.46	0.53	0.53	0.40
0.55	0.54	0.41	0.41	0.41	0.50	0.40	0.39	0.42	0.34	0.38
0.29	0.27	0.19	0.17	0.18	0.21	0.18	0.17	0.17	0.14	0.14
0.32	0.25	0.18	0.18	0.19	0.18	0.16	0.15	0.14	0.12	0.09

Constant HeadTest

Date 15-Apr-07 Water Properties (T= 20C) min min ml s

Sand French Drain A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 ml 8.96825 9.6245 9.8585 10.12475

Clay in suspension 0.5% kaolinite

Time after beginning flow with suspension of fines (min)

	Elevation	Water	Water	Water	Water	Water	Water	Water	0	5	19	37	59	84	123	141	158	190	224	247	277	312	325	340	
Pore volumes									0	0.4	1.4	2.7	4.2	5.7	7.7	8.5	9.2	10.4	11.5	12.2	13.0	14.0	14.3	14.7	
Flow Rate Readings																									
Volume collected (mL)		174	151	125	123	118	112	110		105	101	95	88	80	64	60	53	46	42	40	39	36	36	35	
Time taken to collect (s)		120	120	120	120	120	120	120		120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
Temperature of water (C)		15	15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	
Manometer Readings																									
Point 1 (cm)	1.5	48.4	49.1	49.6	49.8	49.8	50	50		50.1	50.2	50.4	50.5	50.5	50.4	50.5	50.0	49.7	50.3	50.1	50.2	49.8	49.6	49.3	
Point 2 (cm)	3																								
Point 3 (cm)	4.5							47.3		47.3	47.3	47.5	47.6	47.8	48.1	48.3	48.0	47.9	48.6	48.3	48.3	47.6	47.1	47.0	
Point 4 (cm)	8.5							39.7		39.6	39.4	39.0	38.3	37.6	36.2	35.7	35.6	34.3	34.3	34.3	34.3	34.2	34.1	34.2	
Point 5 (cm)	12.5							37.4		37.3	37.1	36.8	36.3	35.8	34.8	34.4	33.9	33.3	33.3	33.3	33.4	33.5	33.6	33.7	
Point 6 (cm)	16.5							35.8		35.8	35.6	35.4	35.0	34.5	33.7	33.3	32.9	32.4	32.4	32.3	32.3	32.2	32.3	32.4	
Point 7 (cm)	20.5							30.1		30.1	30.0	29.9	29.8	29.6	29.4	29.2	29.1	29.0	28.9	28.9	28.8	28.7	28.6	28.6	
Point 8 (cm)	22																								
Point 9 (cm)	23.5	29.1	29	28.8	28.8	28.7	28.7	28.7		28.7	28.6	28.6	28.5	28.5	28.4	28.3	28.3	28.2	28.2	28.2	28.2	28.2	28.2	28.1	

1.258333 mL/s 1.26E-06

1000 mL/L

1000 L/m^3

Calculations

Q (m3/s)		1.45E-06	1.26E-06	1.04E-06	1.03E-06	9.83E-07	9.33E-07	9.17E-07		8.8E-07	8.4E-07	7.9E-07	7.3E-07	6.7E-07	5.3E-07	5E-07	4.42E-07	3.83E-07	3.5E-07	3.33E-07	3.25E-07	3E-07	3E-07	2.92E-07	#DIV/0!
i (Point 1-3)		16.13	16.37	16.53	16.60	16.60	16.67	0.90		0.93	0.97	0.97	0.97	0.90	0.77	0.73	0.67	0.60	0.57	0.60	0.63	0.73	0.83	0.77	0.00
i (Point 1-4)		6.91	7.01	7.09	7.11	7.11	7.14	1.47		1.50	1.54	1.63	1.74	1.84	2.03	2.11	2.06	2.20	2.29	2.26	2.27	2.23	2.21	2.16	0.00
i (Point 1-9)		0.88	0.91	0.95	0.95	0.96	0.97	0.97		0.97	0.98	0.99	1.00	1.00	1.00	1.01	0.99	0.98	1.00	1.00	1.00	0.98	0.97	0.96	0.00
i (Point 6-9)		-4.16	-4.14	-4.11	-4.11	-4.10	-4.10	1.01		1.01	1.00	0.97	0.93	0.86	0.76	0.71	0.66	0.60	0.60	0.59	0.59	0.57	0.59	0.61	0.00
i (Point 3-6)		0.00	0.00	0.00	0.00	0.00	0.00	0.96		0.96	0.98	1.01	1.05	1.11	1.20	1.25	1.26	1.29	1.35	1.33	1.33	1.28	1.23	1.22	0.00
i (Point 4-7)		0.00	0.00	0.00	0.00	0.00	0.00	0.80		0.79	0.78	0.76	0.71	0.67	0.57	0.54	0.54	0.44	0.45	0.45	0.46	0.46	0.46	0.47	0.00

K (m/s)

(Point 1-3)		8.7E-06	7.4E-06	6.1E-06	5.9E-06	5.7E-06	5.4E-06	9.8E-05		9.0E-05	8.4E-05	7.9E-05	7.3E-05	7.1E-05	6.7E-05	6.6E-05	6.4E-05	6.2E-05	5.9E-05	5.3E-05	4.9E-05	3.9E-05	3.5E-05	3.7E-05	#DIV/0!
(Point 1-4)		2.0E-05	1.7E-05	1.4E-05	1.4E-05	1.3E-05	1.3E-05	6.0E-05		5.6E-05	5.3E-05	4.7E-05	4.1E-05	3.5E-05	2.5E-05	2.3E-05	2.1E-05	1.7E-05	1.5E-05	1.4E-05	1.4E-05	1.3E-05	1.3E-05	1.3E-05	#DIV/0!
(Point 1-9)		1.59E-04	1.33E-04	1.06E-04	1.03E-04	9.87E-05	9.28E-05	9.12E-05		8.7E-05	8.3E-05	7.7E-05	7.1E-05	6.4E-05	5.1E-05	4.8E-05	4.3E-05	3.8E-05	3.4E-05	3.2E-05	3.1E-05	2.9E-05	3.0E-05	2.9E-05	#DIV/0!
(Point 6-9)		-3.4E-05	-2.9E-05	-2.4E-05	-2.4E-05	-2.3E-05	-2.2E-05	8.7E-05		8.3E-05	8.1E-05	7.8E-05	7.6E-05	7.5E-05	6.8E-05	6.7E-05	6.5E-05	6.2E-05	5.6E-05	5.5E-05	5.3E-05	5.1E-05	4.9E-05	4.6E-05	#DIV/0!
(Point 3-6)		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	9.2E-05		8.8E-05	8.3E-05	7.6E-05	6.7E-05	5.8E-05	4.3E-05	3.9E-05	3.4E-05	2.9E-05	2.5E-05	2.4E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05	#DIV/0!
(Point 4-7)		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1.1E-04		1.1E-04	1.0E-04	1.0E-04	1.0E-04	9.6E-05	9.1E-05	8.9E-05	7.9E-05	8.4E-05	7.5E-05	7.1E-05	6.8E-05	6.3E-05	6.3E-05	6.0E-05	#DIV/0!

% of Ko (1-3)	Ko =																							
% of Ko (1-4)	Ko =							6.0E-05	1.00	0.94	0.88	0.78	0.68	0.58	0.42	0.38	0.34	0.28	0.25	0.24	0.23	0.22	0.22	0.22
% of Ko (1-9)	Ko =							9.1E-05	1.00	0.95	0.91	0.84	0.77	0.70	0.56	0.52	0.47	0.41	0.37	0.35	0.34	0.32	0.33	0.32
% of Ko (6-9)	Ko =							8.7E-05	1.00	0.95	0.93	0.90	0.87	0.86	0.78	0.77	0.74	0.71	0.65	0.63	0.61	0.58	0.57	0.53

Constant HeadTest

	Test J																						38000	1.06
Date	18-Jun-07																						40280	
Sand	French Drain sand			A (m2)	0.01039																			
Clay in suspension	0.5% (kaolinite)																							

Time after beginning flow with suspension of fines (min)

	Elevation	Water	Water	Water	Water	Water	Water	0	3	6	10	15	24	31	42	58	75	90	106	121	150	170	190
Pore volumes								0	0.7	1.4	2.3	3.4	5.3	6.5	8.2	10.8	13.7	16.1	18.7	21.0	24.8	27.2	29.5
Flow Rate Readings																							
Volume collected (mL)		86	126	119	119	128	128		121	119	114	110	104	108	105	118	115	112	111	97	82	82	80
Time taken to collect (s)		30	45	45	45	45	45		45	45	45	45	45	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																							
Point 1 (cm)	1.5	39.7	40.3	41.1	41.1	40.6	40.7		42.3	43.2	43.9	44.5	45.5	45.9	46.0	46.6	47.1	47.6	48.2	48.6	49.2	49.3	49.3
Point 2 (cm)	3																						
Point 3 (cm)	4.5	37.6	38.5	39.4	39.3	39	39.1		40.5	41.2	41.8	42.3	43.2	43.6	43.3	43.5	43.8	44.6	44.9	45.0	45.4	45.3	45.2
Point 4 (cm)	8.5	34.5	35.5	36	36.1	35.9	36.1		36.6	37.0	37.3	37.3	37.5	37.5	37.9	37.5	37.8	38.1	38.3	38.5	38.5	38.7	38.5
Point 5 (cm)	12.5	32.8	33.8	34.3	34.4	34.3	34.5		34.9	35.4	35.7	35.7	36.0	36.1	36.3	36.0	36.2	36.4	36.6	36.9	36.9	37.0	36.9
Point 6 (cm)	16.5	32.5	33.4	33.8	33.9	33.8	33.9		34.4	34.8	35.1	35.2	35.5	35.6	35.8	35.5	35.8	36.0	36.2	36.5	36.5	36.6	36.4
Point 7 (cm)	20.5	31.6	32.4	32.8	32.9	32.9	33		33.4	33.8	34.2	34.2	34.6	34.7	34.9	34.6	34.9	35.1	35.4	35.7	35.8	36.0	35.8
Point 8 (cm)	22																						
Point 9 (cm)	23.5	29.8	30.2	30	30.2	30.2	30.3		31.2	31.6	32.0	32.0	32.4	32.5	32.8	32.1	32.4	32.6	32.8	33.0	33.2	33.3	33.2
			2.8	mL/s	2.8E-06																		
			1000	mL/L			Turb.	0	726	973	1100												
Calculations			1000	L/m^3																			
Q (m3/s)		2.87E-06	2.8E-06	2.64E-06	2.64E-06	2.84E-06	2.84E-06		2.69E-06	2.64E-06	2.53E-06	2.44E-06	2.31E-06	1.8E-06	1.8E-06	2E-06	1.9E-06	1.9E-06	1.9E-06	1.62E-06	1.37E-06	1.37E-06	1.33E-06
i (Point 1-3)		0.70	0.60	0.57	0.60	0.53	0.53		0.60	0.67	0.70	0.73	0.77	0.77	0.90	1.03	1.10	1.00	1.10	1.20	1.27	1.32	1.37
i (Point 1-4)		0.74	0.69	0.73	0.71	0.67	0.66		0.81	0.89	0.94	1.03	1.14	1.20	1.16	1.30	1.33	1.36	1.41	1.44	1.53	1.51	1.54
i (Point 1-9)		0.45	0.46	0.50	0.50	0.47	0.47		0.50	0.53	0.54	0.57	0.60	0.61	0.60	0.66	0.67	0.68	0.70	0.71	0.73	0.73	0.73
i (Point 6-9)		0.39	0.46	0.54	0.53	0.51	0.51		0.46	0.46	0.44	0.46	0.44	0.44	0.43	0.49	0.49	0.49	0.49	0.50	0.48	0.47	0.46
i (Point 3-6)		0.43	0.43	0.47	0.45	0.43	0.43		0.51	0.53	0.56	0.59	0.64	0.67	0.63	0.67	0.67	0.72	0.73	0.71	0.74	0.73	0.73
i (Point 4-7)		0.24	0.26	0.27	0.27	0.25	0.26		0.27	0.27	0.26	0.26	0.24	0.23	0.25	0.24	0.24	0.25	0.24	0.23	0.23	0.23	0.23
K (m/s)																							
(Point 1-3)		3.9E-04	4.5E-04	4.5E-04	4.2E-04	5.1E-04	5.1E-04		4.3E-04	3.8E-04	3.5E-04	3.2E-04	2.9E-04	2.3E-04	1.9E-04	1.8E-04	1.7E-04	1.8E-04	1.6E-04	1.3E-04	1.0E-04	1.0E-04	9.4E-05
(Point 1-4)		3.7E-04	3.9E-04	3.5E-04	3.6E-04	4.1E-04	4.2E-04		3.2E-04	2.9E-04	2.6E-04	2.3E-04	1.9E-04	1.4E-04	1.5E-04	1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.1E-04	8.6E-05	8.7E-05	8.3E-05
(Point 1-9)		6.1E-04	5.9E-04	5.0E-04	5.1E-04	5.8E-04	5.8E-04		5.1E-04	4.8E-04	4.5E-04	4.1E-04	3.7E-04	2.8E-04	2.8E-04	2.9E-04	2.8E-04	2.6E-04	2.5E-04	2.2E-04	1.8E-04	1.8E-04	1.7E-04
(Point 6-9)		7.2E-04	5.9E-04	4.7E-04	4.8E-04	5.3E-04	5.3E-04		5.7E-04	5.6E-04	5.5E-04	5.1E-04	5.0E-04	3.9E-04	3.9E-04	3.9E-04	3.8E-04	3.7E-04	3.7E-04	3.1E-04	2.7E-04	2.8E-04	2.8E-04
(Point 3-6)		6.5E-04	6.3E-04	5.5E-04	5.7E-04	6.3E-04	6.3E-04		5.1E-04	4.8E-04	4.4E-04	4.0E-04	3.5E-04	2.6E-04	2.7E-04	2.8E-04	2.8E-04	2.5E-04	2.5E-04	2.2E-04	1.8E-04	1.8E-04	1.8E-04
(Point 4-7)		1.1E-03	1.0E-03	9.5E-04	9.5E-04	1.1E-03	1.1E-03		9.7E-04	9.5E-04	9.4E-04	9.1E-04	9.2E-04	7.4E-04	6.7E-04	7.8E-04	7.6E-04	7.2E-04	7.4E-04	6.7E-04	5.8E-04	5.8E-04	5.7E-04
% of Ko (1-3)	Ko =																						
% of Ko (1-4)	Ko =					4.2E-04		1.00	0.76	0.69	0.62	0.55	0.47	0.35	0.35	0.35	0.33	0.32	0.30	0.26	0.21	0.21	0.20
% of Ko (1-9)	Ko =					5.8E-04		1.00	0.89	0.83	0.78	0.72	0.65	0.49	0.48	0.50	0.48	0.46	0.44	0.38	0.31	0.31	0.30
% of Ko (6-9)	Ko =					5.3E-04		1.00	1.06	1.05	1.03	0.97	0.94	0.73	0.74	0.73	0.71	0.69	0.69	0.58	0.52	0.52	0.52

																			660							
																			49500							
22.7	24.6	26.6	27.9	33.1	33.3	33.4	33.7	34.0	34.3	34.7	35.4	36.7	38.2	39.4	40.6	42.0	44.1	45.5	46.4	49.0	51.5	53.8	56.2	58.2	60.9	64.0
					Brine																					
220	246	274	294	373	375	377	380	384	387	392	400	416	434	450	465	483	510	527	538	571	602	629	658	681	712	745
32.9	35.7	38.6	40.6	48.1	48.3	48.5	48.9	49.4	49.8	50.4	51.4	53.3	55.4	57.3	59.0	61.0	64.1	66.0	67.3	71.2	74.9	78.1	81.6	84.5	88.5	92.9
77	72	68	68	63	86	86	87	87	87	85	83	81	80	80	79	78	78	79	79	82	82	83	85	87	90	94
60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
49.7	49.8	50.3	50.4	49.7	48.8	48.7	49.6	49.6	49.7	49.7	49.8	50.1	50.3	50.3	50.5	50.5	50.5	50.4	50.6	50.4	50.2	50.1	50.0	49.9	49.8	49.6
45.3	45.1	45.3	45.3	44.7	46.3	46.3	46.1	46.1	46.1	46.2	46.2	46.4	46.9	46.7	46.8	46.8	46.8	46.8	46.8	46.8	46.8	46.8	46.7	46.6	46.6	46.5
38.5	38.1	38.4	38.0	37.7	38.5	38.7	38.7	38.6	38.7	38.7	38.6	39.0	38.9	39.2	39.3	39.4	39.2	39.0	39.1	39.4	39.5	39.6	39.7	39.6	39.4	39.2
37.0	36.6	36.9	36.5	36.3	36.5	36.6	36.5	36.5	36.5	36.5	36.5	36.6	36.5	36.7	36.8	36.9	36.7	36.5	36.5	36.8	36.9	37.1	37.2	37.2	37.1	37.0
36.5	36.1	36.4	36.0	35.8	35.9	35.9	35.9	35.8	35.9	35.9	35.9	36.0	35.9	36.1	36.1	36.2	36.0	35.8	35.8	36.1	36.2	36.3	36.4	36.4	36.4	36.3
35.8	35.4	35.7	35.2	35.0	34.8	35.0	34.8	34.8	34.9	34.9	34.9	35.1	34.9	35.1	35.1	35.2	34.9	34.7	34.7	34.9	35.2	35.4	35.4	35.4	35.4	35.1
33.2	33.0	33.1	32.6	32.4	32.7	32.6	32.6	32.5	32.6	32.8	32.7	33.0	32.9	33.0	32.9	33.1	33.2	33.0	33.1	33.4	33.7	33.8	33.8	33.8	33.8	33.6
					1100	443	313	89	71	65	26	103	22	22	25	21	12	6.0	5.6	5.2			4.1	4.9	11.6	6.1
1.28E-06	1.2E-06	1.13E-06	1.13E-06	1.05E-06	1.43E-06	1.43E-06	1.45E-06	1.45E-06	1.45E-06	1.42E-06	1.38E-06	1.35E-06	1.33E-06	1.33E-06	1.32E-06	1.3E-06	1.3E-06	1.32E-06	1.32E-06	1.37E-06	1.37E-06	1.38E-06	1.42E-06	1.45E-06	1.5E-06	1.57E-06
1.47	1.55	1.67	1.70	1.65	0.83	0.80	1.17	1.17	1.18	1.15	1.18	1.23	1.12	1.20	1.22	1.23	1.23	1.20	1.27	1.20	1.13	1.10	1.10	1.10	1.07	1.03
1.60	1.66	1.70	1.77	1.71	1.47	1.43	1.56	1.57	1.56	1.56	1.59	1.59	1.62	1.59	1.59	1.59	1.61	1.63	1.64	1.57	1.53	1.50	1.47	1.47	1.49	1.49
0.75	0.76	0.78	0.81	0.79	0.73	0.73	0.78	0.78	0.78	0.77	0.78	0.78	0.79	0.79	0.80	0.79	0.79	0.79	0.80	0.77	0.75	0.74	0.74	0.73	0.73	0.73
0.47	0.44	0.47	0.49	0.49	0.46	0.47	0.48	0.47	0.47	0.44	0.46	0.43	0.43	0.44	0.46	0.44	0.40	0.40	0.39	0.39	0.36	0.36	0.37	0.37	0.37	0.39
0.73	0.75	0.74	0.78	0.74	0.87	0.87	0.85	0.86	0.85	0.86	0.86	0.87	0.92	0.88	0.89	0.88	0.90	0.92	0.92	0.89	0.88	0.88	0.86	0.85	0.85	0.85
0.23	0.23	0.23	0.23	0.23	0.31	0.31	0.33	0.32	0.32	0.32	0.31	0.33	0.33	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.36	0.35	0.36	0.35	0.33	0.34
8.4E-05	7.5E-05	6.5E-05	6.4E-05	6.1E-05	1.7E-04	1.7E-04	1.2E-04	1.2E-04	1.2E-04	1.2E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.0E-04	1.0E-04	1.0E-04	1.1E-04	1.0E-04	1.1E-04	1.2E-04	1.2E-04	1.2E-04	1.3E-04	1.4E-04	1.5E-04
7.7E-05	6.9E-05	6.4E-05	6.2E-05	5.9E-05	9.4E-05	9.7E-05	9.0E-05	8.9E-05	8.9E-05	8.7E-05	8.4E-05	8.2E-05	7.9E-05	8.1E-05	8.0E-05	7.9E-05	7.8E-05	7.8E-05	7.7E-05	8.4E-05	8.6E-05	8.9E-05	9.3E-05	9.5E-05	9.7E-05	1.0E-04
1.6E-04	1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.9E-04	1.9E-04	1.8E-04	1.8E-04	1.8E-04	1.8E-04	1.7E-04	1.7E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.7E-04	1.8E-04	1.8E-04	1.9E-04	1.9E-04	2.0E-04	2.1E-04
2.6E-04	2.6E-04	2.3E-04	2.2E-04	2.1E-04	3.0E-04	2.9E-04	2.9E-04	3.0E-04	3.0E-04	3.1E-04	2.9E-04	3.0E-04	3.0E-04	2.9E-04	2.8E-04	2.8E-04	3.1E-04	3.2E-04	3.3E-04	3.4E-04	3.7E-04	3.7E-04	3.7E-04	3.8E-04	3.9E-04	3.9E-04
1.7E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.5E-04	1.5E-04	1.6E-04	1.6E-04	1.7E-04	1.8E-04
5.5E-04	5.1E-04	4.8E-04	4.7E-04	4.5E-04	4.5E-04	4.5E-04	4.3E-04	4.4E-04	4.4E-04	4.3E-04	4.3E-04	4.0E-04	3.9E-04	3.8E-04	3.6E-04	3.6E-04	3.5E-04	3.5E-04	3.5E-04	3.5E-04	3.7E-04	3.8E-04	3.8E-04	4.0E-04	4.3E-04	4.4E-04
0.19	0.17	0.15	0.15	0.14	0.23	0.23	0.22	0.21	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.21	0.21	0.22	0.23	0.23	0.24
0.28	0.26	0.24	0.23	0.22	0.33	0.33	0.31	0.31	0.31	0.31	0.30	0.29	0.28	0.28	0.27	0.27	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.36
0.49	0.49	0.43	0.42	0.39	0.57	0.55	0.55	0.56	0.56	0.58	0.55	0.57	0.56	0.54	0.52	0.53	0.59	0.60	0.62	0.64	0.69	0.70	0.69	0.71	0.73	0.73

																						1648.64		125		
																								2.083333		
67.3	70.0	70.2	70.4	70.8	71.2	71.5	71.9	72.3	72.8	73.5	74.3	76.0	77.0	78.8	80.3	83.2	90.7	94.2	97.6	101.2	104.5	108.4	117.0	119.3		
		Water																								
780	809	811	813	817	821	824	828	832	837	844	852	868	878	895	910	938	1007	1039	1070	1102	1130	1163	1235	1255		
97.7	101.7	101.9	102.2	102.8	103.4	103.8	104.4	105.0	105.7	106.8	108.0	110.4	111.9	114.4	116.6	120.9	131.6	136.8	141.8	147.0	151.8	157.5	169.8	173.2		
94	96	93	93	99	100	100	101	101	103	105	103	103	103	103	103	105	110	111	111	115	118	120	117	117		
60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60		
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15		
49.6	49.5	48.4	48.3	47.9	47.9	47.9	47.8	47.8	47.9	47.9	47.9	47.9	48.0	48.0	47.9	47.9	47.8	47.5	47.4	47.4	46.6	46.4	46.05	46		
46.6	46.5	45.3	45.3	44.9	44.8	44.8	44.7	44.8	44.8	44.8	45.0	45.1	45.2	45.2	45.2	45.2	45.4	45.2	45.3	45.3	44.4	44.3	43.9	43.9		
39.0	39.0	38.3	38.3	39.6	39.6	39.6	39.6	39.7	39.7	39.8	39.9	40.2	40.3	40.5	40.6	40.6	40.8	40.5	40.6	40.6	39.8	39.6	39.1	39.1		
36.9	36.9	36.7	36.6	37.3	37.3	37.3	37.3	37.4	37.5	37.5	37.6	37.8	37.9	38.0	38.2	38.2	38.3	38.2	38.3	38.1	37.5	37.3	37.1	37.1		
36.2	36.2	36.3	36.1	36.7	36.7	36.7	36.7	36.7	36.9	36.9	37.1	37.2	37.3	37.4	37.5	37.6	37.7	37.5	37.5	37.0	36.9	36.8	36.4	36.4		
35.0	35.0	35.4	35.1	35.7	35.7	35.7	35.7	35.7	35.8	35.9	36.0	36.1	36.2	36.3	36.5	36.4	36.5	36.3	36.4	36.5	35.5	35.3	35	35		
33.5	33.4	34.3	34.1	34.2	34.3	34.3	34.3	34.3	34.5	34.7	34.8	34.9	35.0	35.1	35.1	35.1	35.1	34.7	35.0	34.3	34.0	33.8	33.55	33.6		
5.8	4.9	1100	212	517	296	261	335	367	775	1100												1100	170	146		
1.57E-06	1.6E-06	1.55E-06	1.55E-06	1.65E-06	1.67E-06	1.67E-06	1.68E-06	1.68E-06	1.72E-06	1.75E-06	1.72E-06	1.72E-06	1.72E-06	1.72E-06	1.72E-06	1.75E-06	1.83E-06	1.85E-06	1.85E-06	1.92E-06	1.97E-06	0.000002	1.95E-06	1.95E-06	#DIV/0!	#DIV/0!
1.00	1.00	1.03	0.98	1.00	1.02	1.02	1.03	1.00	1.02	1.02	0.97	0.93	0.92	0.92	0.90	0.88	0.80	0.77	0.70	0.70	0.73	0.70	0.72	0.70	0.00	0.00
1.51	1.50	1.44	1.42	1.19	1.18	1.18	1.17	1.16	1.16	1.15	1.14	1.10	1.09	1.06	1.04	1.04	1.00	1.00	0.97	0.97	0.97	0.97	0.99	0.99	0.00	0.00
0.73	0.73	0.64	0.65	0.62	0.62	0.62	0.62	0.61	0.61	0.60	0.60	0.59	0.59	0.59	0.58	0.58	0.58	0.58	0.56	0.60	0.57	0.57	0.57	0.56	0.00	0.00
0.39	0.40	0.29	0.29	0.36	0.35	0.35	0.35	0.34	0.34	0.32	0.34	0.34	0.34	0.34	0.34	0.36	0.37	0.40	0.36	0.39	0.41	0.43	0.41	0.40	0.00	0.00
0.87	0.86	0.75	0.77	0.68	0.67	0.67	0.67	0.67	0.66	0.66	0.66	0.66	0.66	0.65	0.64	0.63	0.64	0.64	0.65	0.69	0.63	0.63	0.63	0.63	0.00	0.00
0.33	0.33	0.24	0.27	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.34	0.34	0.35	0.34	0.35	0.36	0.35	0.35	0.34	0.36	0.36	0.34	0.34	0.00	0.00
1.5E-04	1.5E-04	1.4E-04	1.5E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.7E-04	1.7E-04	1.8E-04	1.8E-04	1.8E-04	1.8E-04	1.9E-04	2.2E-04	2.3E-04	2.5E-04	2.6E-04	2.6E-04	2.8E-04	2.6E-04	2.7E-04	#DIV/0!	#DIV/0!
1.0E-04	1.0E-04	1.0E-04	1.0E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.4E-04	1.5E-04	1.5E-04	1.6E-04	1.6E-04	1.6E-04	1.8E-04	1.8E-04	1.8E-04	1.9E-04	1.9E-04	2.0E-04	1.9E-04	1.9E-04	#DIV/0!	#DIV/0!
2.1E-04	2.1E-04	2.3E-04	2.3E-04	2.6E-04	2.6E-04	2.6E-04	2.6E-04	2.6E-04	2.7E-04	2.8E-04	2.8E-04	2.8E-04	2.8E-04	2.8E-04	2.8E-04	2.9E-04	3.1E-04	3.1E-04	3.2E-04	3.1E-04	3.3E-04	3.4E-04	3.3E-04	3.3E-04	#DIV/0!	#DIV/0!
3.9E-04	3.9E-04	5.1E-04	5.1E-04	4.4E-04	4.6E-04	4.6E-04	4.6E-04	4.7E-04	4.8E-04	5.2E-04	4.9E-04	4.9E-04	4.9E-04	4.9E-04	4.8E-04	4.6E-04	4.8E-04	4.5E-04	5.0E-04	4.8E-04	4.6E-04	4.5E-04	4.6E-04	4.7E-04	#DIV/0!	#DIV/0!
1.7E-04	1.8E-04	2.0E-04	1.9E-04	2.3E-04	2.4E-04	2.4E-04	2.4E-04	2.4E-04	2.5E-04	2.6E-04	2.5E-04	2.5E-04	2.5E-04	2.5E-04	2.6E-04	2.7E-04	2.8E-04	2.8E-04	2.7E-04	2.7E-04	3.0E-04	3.1E-04	3.0E-04	3.0E-04	#DIV/0!	#DIV/0!
4.5E-04	4.6E-04	6.2E-04	5.6E-04	4.9E-04	4.9E-04	4.9E-04	5.0E-04	4.9E-04	5.1E-04	5.2E-04	5.1E-04	4.8E-04	4.8E-04	4.7E-04	4.8E-04	4.8E-04	4.9E-04	5.1E-04	5.1E-04	5.4E-04	5.3E-04	5.4E-04	5.5E-04	5.5E-04	#DIV/0!	#DIV/0!
0.24	0.25	0.25	0.25	0.32	0.33	0.33	0.33	0.34	0.34	0.35	0.35	0.36	0.36	0.37	0.38	0.39	0.42	0.43	0.44	0.46	0.47	0.48	0.45	0.46		
0.36	0.36	0.40	0.40	0.44	0.45	0.45	0.45	0.46	0.47	0.48	0.48	0.48	0.48	0.49	0.49	0.50	0.53	0.53	0.55	0.53	0.57	0.58	0.57	0.57		
0.73	0.72	0.96	0.96	0.84	0.86	0.86	0.87	0.89	0.91	0.98	0.92	0.92	0.92	0.92	0.91	0.87	0.89	0.84	0.94	0.90	0.86	0.84	0.87	0.88		

Constant HeadTest

min ml s

ml s min

Date May 22, 2007

Sand French Drain sand A (m2) 0.01039

Clay in suspension 0.5% (kaolinite)

Water Properties (T= 20C) K (length^2) is 1.047 times higher with salt water than with fresh water.

γ (kN/m3) 10.1

μ (Ns/m2) 1.1E-03 0.00011

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	3	7	13	21	34	49	72	103	138	170	204	232	265	299	345
Pore volumes								0	0.5	1.1	2.0	3.2	5.1	7.1	9.9	13.3	16.6	19.4	22.2	24.3	26.7	29.1	32.3
Flow Rate Readings																							
Volume collected (mL)		136	133	123	111	111			109	106	102	102	98	88	80	69	124	60	107	100	99	97	93
Time taken to collect (s)		60	60	60	60	60	60		60	60	60	60	60	60	60	60	120	60	120	120	120	120	120
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																							
Point 1 (cm)	1.5	42.4	43.5	44.1	45.5	45.5			45.8	46.0	46.1	46.3	46.6	46.8	47.0	46.7	46.9	47.3	47.6	47.8	48.0	48.1	47.6
Point 2 (cm)	3																						
Point 3 (cm)	4.5	41.1	42.5	43.1	44.5	44.6			44.8	45.0	45.2	45.3	45.6	45.9	46.1	46.1	46.4	46.8	47.0	47.2	47.4	47.5	47.1
Point 4 (cm)	8.5	37.8	39.6	40.1	41.3	41.5			41.6	41.2	41.7	41.9	42.0	42.1	42.2	42.2	42.3	42.8	43.1	43.3	43.2	43.8	43.3
Point 5 (cm)	12.5	35.8	37.6	38	39.1	39.3			39.3	39.4	39.4	39.5	39.7	39.8	39.9	40.0	40.0	40.6	41.0	41.3	41.5	41.7	41.3
Point 6 (cm)	16.5	33	34.1	34.4	35.1	35.3			35.2	35.2	35.3	35.3	35.3	35.3	35.1	35.5	35.3	35.7	36.1	36.5	37.0	37.2	36.7
Point 7 (cm)	20.5	31.3	32	32.2	32.2	32.3			32.3	32.3	32.3	32.3	32.3	32.3	32.3	32.2	32.2	32.0	32.8	33.1	33.5	33.8	33.5
Point 8 (cm)	22																						
Point 9 (cm)	23.5	29.5	29.4	29.3	29.2	29.3			29.3	29.3	29.3	29.2	29.2	29.2	29.1	29.0	28.9	29.0	29.1	29.1	29.2	29.2	29.5
			2.216667 mL/s		2.22E-06																		
			1000 mL/L					Turb.	50	308	635	958	1100										
Calculations			1000 L/m^3																				
Q (m3/s)		2.27E-06	2.22E-06	2.05E-06	1.85E-06	1.85E-06	0		1.82E-06	1.77E-06	1.7E-06	1.7E-06	1.63E-06	1.47E-06	1.333E-06	0.00000115	1.0333E-06	0.000001	8.9167E-07	8.3333E-07	8.25E-07	8.0833E-07	7.75E-07
i (Point 1-3)		0.43	0.33	0.33	0.33	0.30	0.00		0.33	0.33	0.30	0.33	0.33	0.30	0.30	0.20	0.17	0.17	0.20	0.20	0.20	0.20	0.17
i (Point 1-4)		0.66	0.56	0.57	0.60	0.57	0.00		0.60	0.69	0.63	0.63	0.66	0.67	0.69	0.64	0.66	0.64	0.64	0.64	0.69	0.61	0.61
i (Point 1-9)		0.59	0.64	0.67	0.74	0.74	0.00		0.75	0.76	0.76	0.78	0.79	0.80	0.81	0.80	0.82	0.83	0.84	0.85	0.85	0.86	0.82
i (Point 6-9)		0.50	0.67	0.73	0.84	0.86	0.00		0.84	0.84	0.86	0.87	0.87	0.87	0.86	0.93	0.91	0.96	1.00	1.06	1.11	1.14	1.03
i (Point 3-4)		0.83	0.73	0.75	0.80	0.78	0.00		0.80	0.95	0.88	0.85	0.90	0.95	0.98	0.98	1.03	1.00	0.98	0.98	1.05	0.93	0.95
i (Point 4-5)		0.50	0.50	0.53	0.55	0.55	0.00		0.58	0.45	0.58	0.60	0.57	0.58	0.58	0.55	0.57	0.55	0.53	0.50	0.43	0.52	0.50
i (Point 5-6)		0.70	0.88	0.90	1.00	1.00	0.00		1.03	1.05	1.03	1.05	1.10	1.13	1.20	1.13	1.18	1.23	1.23	1.20	1.13	1.13	1.15
i (Point 6-7)		0.43	0.53	0.55	0.73	0.75	0.00		0.73	0.73	0.75	0.75	0.75	0.75	0.70	0.82	0.77	0.93	0.83	0.85	0.88	0.85	0.80
i (Point 7-9)		0.60	0.87	0.97	1.00	1.00	0.00		1.00	1.00	1.00	1.03	1.03	1.03	1.07	1.07	1.10	1.00	1.23	1.33	1.43	1.53	1.33
K (m/s)																							
(Point 1-3)		5.0E-04	6.4E-04	5.9E-04	5.3E-04	5.9E-04	#DIV/0!		5.2E-04	5.1E-04	5.5E-04	4.9E-04	4.7E-04	4.7E-04	4.3E-04	5.5E-04	6.0E-04	5.8E-04	4.3E-04	4.0E-04	4.0E-04	3.9E-04	4.5E-04
(Point 1-4)		3.3E-04	3.8E-04	3.5E-04	3.0E-04	3.1E-04	#DIV/0!		2.9E-04	2.5E-04	2.6E-04	2.6E-04	2.4E-04	2.1E-04	1.9E-04	1.7E-04	1.5E-04	1.5E-04	1.3E-04	1.2E-04	1.2E-04	1.3E-04	1.2E-04
(Point 1-9)		3.7E-04	3.3E-04	2.9E-04	2.4E-04	2.4E-04	#DIV/0!		2.3E-04	2.2E-04	2.1E-04	2.1E-04	2.0E-04	1.8E-04	1.6E-04	1.4E-04	1.2E-04	1.2E-04	1.0E-04	9.4E-05	9.3E-05	9.1E-05	9.1E-05
(Point 6-9)		4.4E-04	3.2E-04	2.7E-04	2.1E-04	2.1E-04	#DIV/0!		2.1E-04	2.0E-04	1.9E-04	1.9E-04	1.8E-04	1.6E-04	1.5E-04	1.2E-04	1.1E-04	1.0E-04	8.6E-05	7.6E-05	7.1E-05	6.8E-05	7.3E-05
(Point 3-4)		2.6E-04	2.9E-04	2.6E-04	2.2E-04	2.3E-04	#DIV/0!		2.2E-04	1.8E-04	1.9E-04	1.9E-04	1.7E-04	1.5E-04	1.3E-04	1.1E-04	9.7E-05	9.6E-05	8.8E-05	8.2E-05	7.6E-05	8.4E-05	7.9E-05
(Point 4-5)		4.4E-04	4.3E-04	3.8E-04	3.2E-04	3.2E-04	#DIV/0!		3.0E-04	3.8E-04	2.8E-04	2.7E-04	2.7E-04	2.5E-04	2.2E-04	2.0E-04	1.7E-04	1.8E-04	1.6E-04	1.6E-04	1.9E-04	1.5E-04	1.5E-04
(Point 5-6)		3.1E-04	2.4E-04	2.2E-04	1.8E-04	1.8E-04	#DIV/0!		1.7E-04	1.6E-04	1.6E-04	1.6E-04	1.4E-04	1.3E-04	1.1E-04	9.8E-05	8.5E-05	7.9E-05	7.0E-05	6.7E-05	7.1E-05	6.9E-05	6.5E-05
(Point 6-7)		5.1E-04	4.1E-04	3.6E-04	2.5E-04	2.4E-04	#DIV/0!		2.4E-04	2.3E-04	2.2E-04	2.2E-04	2.1E-04	1.9E-04	1.8E-04	1.3E-04	1.3E-04	1.0E-04	1.0E-04	9.4E-05	9.1E-05	9.2E-05	9.3E-05
(Point 7-9)		3.6E-04	2.5E-04	2.0E-04	1.8E-04	1.8E-04	#DIV/0!		1.7E-04	1.7E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04	1.2E-04	1.0E-04	9.0E-05	9.6E-05	7.0E-05	6.0E-05	5.5E-05	5.1E-05	5.6E-05

% of Ko (1-4)	Ko =					3.0E-04		1.00	0.98	0.84	0.88	0.88	0.81	0.71	0.63	0.58	0.51	0.50	0.45	0.42	0.39	0.43	0.41
% of Ko (1-9)	Ko =					2.4E-04		1.00	0.97	0.93	0.89	0.88	0.83	0.73	0.66	0.57	0.51	0.48	0.42	0.39	0.39	0.38	0.38
% of Ko (6-9)	Ko =					2.1E-04		1.00	0.98	0.95	0.90	0.89	0.85	0.77	0.71	0.56	0.51	0.48	0.41	0.36	0.34	0.32	0.34
% of Ko (1-3)	Ko =					5.9E-04		1.00	0.88	0.86	0.92	0.83	0.79	0.79	0.72	0.93	1.01	0.97	0.72	0.68	0.67	0.66	0.75
% of Ko (3-4)	Ko =					2.3E-04		1.00	0.95	0.78	0.81	0.84	0.76	0.65	0.57	0.49	0.42	0.42	0.38	0.36	0.33	0.37	0.34
% of Ko (4-5)	Ko =					3.2E-04		1.00	0.94	1.17	0.88	0.84	0.84	0.76	0.69	0.62	0.53	0.54	0.50	0.50	0.58	0.46	0.46
% of Ko (5-6)	Ko =					1.8E-04		1.00	0.96	0.91	0.90	0.88	0.80	0.70	0.60	0.55	0.48	0.44	0.39	0.38	0.40	0.39	0.36
% of Ko (6-7)	Ko =					2.4E-04		1.00	1.02	0.99	0.92	0.92	0.88	0.79	0.77	0.57	0.54	0.44	0.44	0.40	0.38	0.39	0.39
% of Ko (7-9)	Ko =					1.8E-04		1.00	0.98	0.95	0.92	0.89	0.85	0.77	0.68	0.58	0.51	0.54	0.39	0.34	0.31	0.28	0.31

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
FD-1		1248.09	1217.70	30.39	2.4%	1
FD-2		1273.81	1226.15	47.66	3.7%	3
FD-3		1315.21	1274.59	40.62	3.1%	1

Post-test total mass of fines 119 g

Mass of fines injected 118 g

Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

Note: This sample was injected with brine and fresh water cycled after being clogged with fines. The amount of fines in the sample following the test is roughly equivalent to the pre-test amount.

	118	g																	660 49500			
23.1	23.5	23.7	24.0	24.4	25.3	27.1	28.7	32.0	35.2	38.0	43.2	45.6	49.1	51.6	54.5	57.5	60.9	82.8	119.8	120.1	120.7	121.6
		Brine																		Water		
364	374	377	382	388	401	430	457	509	559	601	676	710	758	792	830	870	915	1210	1732	1735	1742	1751
33.5	34.2	34.4	34.9	35.5	36.7	39.3	41.7	46.4	51.1	55.2	62.7	66.2	71.3	74.9	79.1	83.5	88.5	120.3	174.0	174.4	175.3	176.5
85	85	69	65	131	127	123	122	128	132	135	70	72	73	75	76	76	76	145	104	94	92	94
120	120	60	60	120	120	120	120	120	120	120	60	60	60	60	60	60	60	120	90	60	60	60
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
47.6	47.7	48.5	48.5	48.6	48.7	48.8	48.8	48.7	48.5	48.3	47.7	47.5	47.2	47.1	46.9	46.8	46.8	46.5	46.1	46.1	45.8	46.0
46.8	46.9	47.5	47.5	47.6	47.7	47.7	47.7	47.7	47.5	47.2	46.6	46.3	46.0	45.7	45.5	45.3	45.3	44.7	43.9	45.0	44.7	44.9
43.2	43.3	44.3	44.3	44.4	44.6	44.7	44.7	44.7	44.6	44.2	43.6	43.3	42.8	42.5	42.3	42.0	41.9	41.2	40.3	41.9	41.7	41.7
41.3	41.3	42.1	42.2	42.3	42.5	42.7	42.7	42.7	42.6	42.3	41.7	41.4	41.0	40.7	40.4	40.1	40.0	39.1	38.3	40.0	39.9	40.0
36.8	37.0	37.2	37.2	37.3	37.4	37.3	37.2	37.3	37.5	37.6	37.6	37.6	37.3	37.1	36.9	36.7	36.6	36.0	35.4	36.8	36.7	36.8
33.6	33.7	33.3	33.3	33.4	33.5	33.9	33.8	33.7	33.9	34.0	34.1	34.2	34.1	34.1	34.0	33.8	33.8	33.5	33.2	34.2	34.1	34.2
29.5	29.5	27.5	27.5	27.5	27.5	27.5	27.5	27.8	27.9	27.9	27.9	28.0	28.0	27.9	27.9	27.9	28.0	28.0	28.2	29.4	29.8	29.8
		1100	93	21.8	10.1	4.5	3.5	30.0	6.4	5.2	5.0	3.9	4.2	3.4		3.0		1.8	1.5	762.0	697	1100
7.08333E-07	7.08333E-07	0.00000115	1.08333E-06	1.09167E-06	1.05833E-06	0.000001025	1.01667E-06	1.06667E-06	1.1E-06	1.13E-06	1.17E-06	1.2E-06	1.22E-06	1.25E-06	1.27E-06	1.27E-06	1.27E-06	1.21E-06	1.16E-06	1.57E-06	1.53E-06	1.57E-06
0.27	0.27	0.33	0.33	0.33	0.33	0.37	0.37	0.33	0.33	0.37	0.37	0.40	0.40	0.47	0.47	0.50	0.50	0.60	0.73	0.37	0.37	0.37
0.63	0.63	0.60	0.60	0.60	0.59	0.59	0.59	0.57	0.56	0.59	0.59	0.60	0.63	0.66	0.66	0.69	0.70	0.76	0.83	0.60	0.59	0.61
0.82	0.83	0.95	0.95	0.96	0.96	0.97	0.97	0.95	0.94	0.93	0.90	0.89	0.87	0.87	0.86	0.86	0.85	0.84	0.81	0.76	0.73	0.74
1.04	1.07	1.39	1.39	1.40	1.41	1.40	1.39	1.36	1.37	1.39	1.39	1.37	1.33	1.31	1.29	1.26	1.23	1.14	1.03	1.06	0.99	1.00
0.90	0.90	0.80	0.80	0.80	0.78	0.75	0.75	0.75	0.73	0.75	0.75	0.75	0.80	0.80	0.80	0.82	0.85	0.88	0.90	0.78	0.75	0.80
0.48	0.50	0.55	0.52	0.53	0.53	0.50	0.50	0.50	0.50	0.48	0.48	0.48	0.45	0.45	0.48	0.48	0.48	0.53	0.50	0.48	0.45	0.43
1.13	1.08	1.23	1.25	1.25	1.28	1.35	1.38	1.35	1.28	1.18	1.03	0.95	0.93	0.90	0.88	0.85	0.85	0.78	0.73	0.80	0.80	0.80
0.80	0.82	0.98	0.98	0.98	0.98	0.85	0.85	0.90	0.90	0.90	0.88	0.85	0.80	0.75	0.73	0.73	0.70	0.63	0.55	0.65	0.65	0.65
1.37	1.40	1.93	1.93	1.97	2.00	2.13	2.10	1.97	2.00	2.03	2.07	2.07	2.03	2.07	2.03	1.97	1.93	1.83	1.67	1.60	1.43	1.47
										K (m/s)												
2.6E-04	2.6E-04	3.3E-04	3.1E-04	3.2E-04	3.1E-04	2.7E-04	2.7E-04	3.1E-04	3.2E-04	3.0E-04	3.1E-04	2.9E-04	2.9E-04	2.6E-04	2.6E-04	2.4E-04	2.4E-04	1.9E-04	1.5E-04	4.1E-04	4.0E-04	4.1E-04
1.1E-04	1.1E-04	1.8E-04	1.7E-04	1.8E-04	1.7E-04	1.7E-04	1.7E-04	1.8E-04	1.9E-04	1.8E-04	1.9E-04	1.9E-04	1.9E-04	1.8E-04	1.9E-04	1.8E-04	1.7E-04	1.5E-04	1.3E-04	2.5E-04	2.5E-04	2.5E-04
8.3E-05	8.2E-05	1.2E-04	1.1E-04	1.1E-04	1.1E-04	1.0E-04	1.0E-04	1.1E-04	1.1E-04	1.2E-04	1.2E-04	1.3E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	2.0E-04	2.0E-04	2.0E-04
6.5E-05	6.4E-05	8.0E-05	7.5E-05	7.5E-05	7.2E-05	7.0E-05	7.1E-05	7.6E-05	7.7E-05	7.8E-05	8.1E-05	8.4E-05	8.8E-05	9.2E-05	9.5E-05	9.7E-05	9.9E-05	1.0E-04	1.1E-04	1.4E-04	1.5E-04	1.5E-04
7.6E-05	7.6E-05	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.4E-04	1.5E-04	1.4E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.3E-04	1.2E-04	1.9E-04	2.0E-04	1.9E-04
1.4E-04	1.4E-04	2.0E-04	2.0E-04	2.0E-04	1.9E-04	2.0E-04	2.0E-04	2.1E-04	2.1E-04	2.3E-04	2.4E-04	2.4E-04	2.6E-04	2.7E-04	2.6E-04	2.6E-04	2.6E-04	2.2E-04	2.2E-04	3.2E-04	3.3E-04	3.5E-04
6.1E-05	6.3E-05	9.0E-05	8.3E-05	8.4E-05	8.0E-05	7.3E-05	7.1E-05	7.6E-05	8.3E-05	9.2E-05	1.1E-04	1.2E-04	1.3E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.5E-04	1.9E-04	1.8E-04	1.9E-04
8.5E-05	8.3E-05	1.1E-04	1.1E-04	1.1E-04	1.0E-04	1.2E-04	1.2E-04	1.1E-04	1.2E-04	1.2E-04	1.3E-04	1.4E-04	1.5E-04	1.6E-04	1.7E-04	1.7E-04	1.7E-04	1.9E-04	2.0E-04	2.3E-04	2.3E-04	2.3E-04
5.0E-05	4.9E-05	5.7E-05	5.4E-05	5.3E-05	5.1E-05	4.6E-05	4.7E-05	5.2E-05	5.3E-05	5.3E-05	5.4E-05	5.6E-05	5.8E-05	5.8E-05	6.0E-05	6.2E-05	6.3E-05	6.3E-05	6.7E-05	9.4E-05	1.0E-04	1.0E-04
0.37	0.37	0.62	0.59	0.59	0.59	0.57	0.56	0.61	0.64	0.62	0.65	0.65	0.63	0.62	0.63	0.60	0.59	0.52	0.45	0.85	0.85	0.83
0.34	0.34	0.48	0.45	0.46	0.44	0.42	0.42	0.45	0.47	0.49	0.52	0.54	0.56	0.57	0.59	0.59	0.59	0.58	0.57	0.83	0.84	0.85
0.31	0.30	0.38	0.36	0.36	0.34	0.33	0.33	0.36	0.37	0.37	0.38	0.40	0.42	0.43	0.45	0.46	0.47	0.48	0.51	0.68	0.71	0.71
0.43	0.43	0.56	0.53	0.53	0.51	0.45	0.45	0.52	0.54	0.50	0.52	0.49	0.49	0.43	0.44	0.41	0.41	0.33	0.26	0.69	0.68	0.69
0.33	0.33	0.60	0.57	0.57	0.57	0.57	0.57	0.60	0.64	0.63	0.65	0.67	0.64	0.65	0.66	0.64	0.62	0.58	0.54	0.85	0.86	0.82
0.44	0.42	0.62	0.61	0.62	0.60	0.61	0.60	0.63	0.65	0.70	0.73	0.75	0.80	0.83	0.79	0.79	0.79	0.68	0.69	0.98	1.01	1.10
0.34	0.36	0.51	0.47	0.47	0.45	0.41	0.40	0.43	0.47	0.52	0.62	0.68	0.71	0.75	0.78	0.81	0.81	0.84	0.86	1.06	1.04	1.06
0.36	0.35	0.48	0.45	0.45	0.44	0.49	0.48	0.48	0.50	0.51	0.54	0.57	0.62	0.68	0.71	0.71	0.73	0.78	0.85	0.98	0.96	0.98
0.28	0.27	0.32	0.30	0.30	0.29	0.26	0.26	0.29	0.30	0.30	0.31	0.31	0.32	0.33	0.34	0.35	0.35	0.36	0.37	0.53	0.58	0.58

122.3	125.1	127.6	130.1	132.1	134.7	137.1	141.3	146.5	151.0	156.2	158.3	162.6
1759	1790	1821	1855	1882	1916	1949	2004	2070	2126	2190	2216	2268
177.6	181.6	185.2	189.0	191.9	195.6	199.1	205.2	212.8	219.3	226.8	229.9	236.1
96	82	77	74	75	74	75	78	80	80	81	82	84
60	60	60	60	60	60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15	15	15	15	15	15
46.2	47.3	48.0	48.4	48.4	48.4	48.3	48.0	47.6	47.4	47.2	47.3	47.1
45.2	46.5	47.3	47.5	47.5	47.6	47.4	47.1	46.8	46.5	46.2	46.2	46.1
42.0	43.4	44.3	44.8	44.8	44.8	44.6	44.1	43.6	43.3	42.9	42.9	42.9
40.1	41.4	42.4	42.9	43.0	43.0	42.8	42.3	41.7	41.4	41.0	40.9	41.0
36.8	37.5	38.2	38.6	38.7	38.9	38.9	38.6	37.9	37.5	37.1	37.0	37.1
34.2	34.5	34.9	35.2	35.1	35.2	35.2	35.1	34.8	34.6	34.4	34.4	34.4
29.3	29.3	29.1	28.9	29.0	29.2	29.3	29.3	29.5	29.6	29.7	29.6	29.6
											1100.0	22.7
1.6E-06	1.37E-06	1.28E-06	1.23E-06	1.25E-06	1.23E-06	1.25E-06	1.3E-06	1.33E-06	1.33E-06	1.35E-06	1.37E-06	1.4E-06
0.33	0.27	0.23	0.30	0.30	0.27	0.30	0.30	0.27	0.30	0.33	0.37	0.33
0.60	0.56	0.53	0.51	0.51	0.51	0.53	0.56	0.57	0.59	0.61	0.63	0.60
0.77	0.82	0.86	0.89	0.88	0.87	0.86	0.85	0.82	0.81	0.80	0.80	0.80
1.07	1.17	1.30	1.39	1.39	1.39	1.37	1.33	1.20	1.13	1.06	1.06	1.07
0.80	0.78	0.75	0.68	0.68	0.70	0.70	0.75	0.80	0.80	0.83	0.83	0.80
0.48	0.50	0.48	0.48	0.45	0.45	0.45	0.45	0.48	0.48	0.48	0.50	0.48
0.83	0.98	1.05	1.08	1.08	1.03	0.98	0.92	0.95	0.98	0.98	0.98	0.98
0.65	0.75	0.83	0.85	0.90	0.92	0.92	0.88	0.78	0.73	0.68	0.65	0.68
1.63	1.73	1.93	2.10	2.03	2.00	1.97	1.93	1.77	1.67	1.57	1.60	1.60
												K (m/s)
4.6E-04	4.9E-04	5.3E-04	4.0E-04	4.0E-04	4.5E-04	4.0E-04	4.2E-04	4.8E-04	4.3E-04	3.9E-04	3.6E-04	4.0E-04
2.6E-04	2.4E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.3E-04	2.2E-04	2.2E-04	2.2E-04	2.1E-04	2.1E-04	2.2E-04
2.0E-04	1.6E-04	1.4E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.7E-04
1.4E-04	1.1E-04	9.5E-05	8.6E-05	8.7E-05	8.6E-05	8.8E-05	9.4E-05	1.1E-04	1.1E-04	1.2E-04	1.2E-04	1.3E-04
1.9E-04	1.7E-04	1.6E-04	1.8E-04	1.8E-04	1.7E-04	1.7E-04	1.7E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.7E-04
3.2E-04	2.6E-04	2.6E-04	2.5E-04	2.7E-04	2.6E-04	2.7E-04	2.8E-04	2.7E-04	2.7E-04	2.7E-04	2.6E-04	2.8E-04
1.9E-04	1.3E-04	1.2E-04	1.1E-04	1.1E-04	1.2E-04	1.2E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.4E-04
2.4E-04	1.8E-04	1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.4E-04	1.7E-04	1.8E-04	1.9E-04	2.0E-04	2.0E-04
9.4E-05	7.6E-05	6.4E-05	5.7E-05	5.9E-05	5.9E-05	6.1E-05	6.5E-05	7.3E-05	7.7E-05	8.3E-05	8.2E-05	8.4E-05
0.86	0.80	0.79	0.78	0.79	0.78	0.77	0.76	0.76	0.74	0.71	0.71	0.76
0.83	0.67	0.60	0.56	0.57	0.57	0.58	0.61	0.65	0.66	0.68	0.68	0.70
0.68	0.53	0.45	0.41	0.41	0.41	0.42	0.45	0.51	0.54	0.58	0.59	0.60
0.78	0.83	0.89	0.67	0.68	0.75	0.68	0.70	0.81	0.72	0.66	0.60	0.68
0.84	0.74	0.72	0.77	0.78	0.74	0.75	0.73	0.70	0.70	0.69	0.69	0.73
1.00	0.81	0.80	0.77	0.83	0.81	0.83	0.86	0.83	0.83	0.84	0.81	0.88
1.05	0.76	0.66	0.62	0.63	0.65	0.69	0.76	0.76	0.74	0.75	0.76	0.78
1.00	0.74	0.63	0.59	0.56	0.54	0.55	0.60	0.70	0.75	0.81	0.85	0.84
0.53	0.43	0.36	0.32	0.33	0.33	0.34	0.36	0.41	0.43	0.47	0.46	0.47

165.6	173.5	190.2	237.9	244.5	252.8	256.7	260.0	262.6	266.3	271.8	277.4	281.6
2303	2398	2604	3165	3238	3332	3377	3416	3446	3487	3548	3610	3657
240.4	251.9	276.2	345.4	355.1	367.1	372.7	377.6	381.4	386.7	394.7	402.8	409.0
85	82	80	90	92	85	85	87	87	91	90	90	91
60	60	60	60	60	60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15	15	15	15	15	15
47.1	47.4	47.4	45.8	46.2	46.8	46.7	46.6	46.5	46.3	46.1	45.9	45.8
46.2	46.4	46.4	44.6	45.2	45.8	45.7	45.5	45.4	45.2	44.9	44.8	44.7
42.9	43.2	43.3	40.8	41.6	42.5	42.4	42.2	42.0	41.8	41.5	41.3	41.2
41.0	41.5	41.6	38.8	39.6	40.6	40.6	40.4	40.2	39.9	39.5	39.2	39.2
37.1	37.7	37.9	34.5	35.4	36.6	36.6	36.5	36.3	36.0	35.5	35.2	35.1
34.5	35.1	35.3	32.4	33.2	34.2	34.3	34.2	34.1	33.8	33.4	33.3	33.1
29.7	30.0	30.0	29.5	29.8	29.9	30.0	30.0	30.0	30.0	29.9	29.8	29.8
3.4	1.2		1.2						0.7	0.6	1.0	0.7
1.42E-06	1.37E-06	1.33E-06	1.5E-06	1.53E-06	1.42E-06	1.42E-06	1.45E-06	1.45E-06	1.52E-06	1.5E-06	1.5E-06	1.52E-06
0.30	0.33	0.33	0.40	0.33	0.33	0.33	0.37	0.37	0.37	0.40	0.37	0.37
0.60	0.60	0.59	0.71	0.66	0.61	0.61	0.63	0.64	0.64	0.66	0.66	0.66
0.79	0.79	0.79	0.74	0.75	0.77	0.76	0.75	0.75	0.74	0.74	0.73	0.73
1.06	1.10	1.13	0.71	0.80	0.96	0.94	0.93	0.90	0.86	0.80	0.77	0.76
0.83	0.80	0.78	0.95	0.90	0.82	0.83	0.82	0.85	0.85	0.85	0.88	0.88
0.48	0.43	0.42	0.50	0.50	0.48	0.45	0.45	0.45	0.48	0.50	0.52	0.50
0.98	0.95	0.93	1.08	1.05	1.00	1.00	0.98	0.98	0.98	1.00	1.00	1.03
0.65	0.65	0.65	0.53	0.55	0.60	0.58	0.57	0.55	0.55	0.53	0.48	0.50
1.60	1.70	1.77	0.97	1.13	1.43	1.43	1.40	1.37	1.27	1.17	1.17	1.10
4.5E-04	3.9E-04	3.9E-04	3.6E-04	4.4E-04	4.1E-04	4.1E-04	3.8E-04	3.8E-04	4.0E-04	3.6E-04	3.9E-04	4.0E-04
2.3E-04	2.2E-04	2.2E-04	2.0E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.2E-04	2.3E-04	2.2E-04	2.2E-04	2.2E-04
1.7E-04	1.7E-04	1.6E-04	1.9E-04	2.0E-04	1.8E-04	1.8E-04	1.9E-04	1.9E-04	2.0E-04	2.0E-04	2.0E-04	2.0E-04
1.3E-04	1.2E-04	1.1E-04	2.0E-04	1.8E-04	1.4E-04	1.4E-04	1.5E-04	1.6E-04	1.7E-04	1.8E-04	1.9E-04	1.9E-04
1.7E-04	1.6E-04	1.7E-04	1.5E-04	1.6E-04	1.7E-04	1.7E-04	1.7E-04	1.6E-04	1.7E-04	1.7E-04	1.7E-04	1.7E-04
2.9E-04	3.1E-04	3.0E-04	2.9E-04	3.0E-04	2.9E-04	3.0E-04	3.1E-04	3.1E-04	3.1E-04	2.9E-04	2.8E-04	2.9E-04
1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04
2.1E-04	2.0E-04	2.0E-04	2.8E-04	2.7E-04	2.3E-04	2.4E-04	2.4E-04	2.5E-04	2.7E-04	2.8E-04	3.0E-04	2.9E-04
8.5E-05	7.7E-05	7.3E-05	1.5E-04	1.3E-04	9.5E-05	9.5E-05	1.0E-04	1.0E-04	1.2E-04	1.2E-04	1.2E-04	1.3E-04
0.77	0.74	0.74	0.68	0.76	0.75	0.75	0.75	0.73	0.77	0.74	0.74	0.75
0.72	0.69	0.68	0.81	0.82	0.74	0.75	0.77	0.77	0.82	0.82	0.82	0.84
0.61	0.57	0.54	0.96	0.87	0.67	0.68	0.71	0.73	0.81	0.85	0.89	0.91
0.77	0.66	0.65	0.61	0.75	0.69	0.69	0.64	0.64	0.67	0.61	0.66	0.67
0.72	0.72	0.72	0.66	0.71	0.72	0.72	0.74	0.71	0.75	0.74	0.72	0.73
0.89	0.96	0.93	0.89	0.91	0.89	0.94	0.96	0.96	0.95	0.89	0.85	0.90
0.79	0.78	0.78	0.75	0.79	0.77	0.77	0.80	0.80	0.84	0.81	0.81	0.80
0.88	0.85	0.83	1.16	1.13	0.96	1.00	1.02	1.07	1.12	1.16	1.28	1.23
0.48	0.43	0.41	0.84	0.73	0.53	0.53	0.56	0.57	0.65	0.69	0.69	0.75

French Drain sand
Tare 401.91
Pre-wash 2278.6

1648.64		125				8.6	0.516										
		2.083333					0.43										
281.9	282.5	283.6	314.8	321.9	322.1	322.7	323.6	324.5	326.5	327.1	328.4	329.5	387.3	389.6	399.4	401.8	litres
Brine					Water											82.4	hours
3660	3666	3677	4024	4110	4113	4119	4129	4138	4158	4165	4179	4190	4796	4819	4920	4945	
409.4	410.2	411.8	457.1	467.4	467.8	468.6	470.0	471.2	474.0	475.0	476.9	478.4	562.5	565.7	580.0	583.5	
98	98	98	82	82	94	94	96	98	96	95	93	93	98	99	96	95	
60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	
45.8	45.8	45.8	46.6	46.5	46.4	46.4	46.5	46.7	46.9	47	47	47	45.7	45.7	46	46.1	
44.7	44.7	44.7	45.4	45.2	44.7	44.8	45	45.2	45.5	45.6	45.7	45.6	44.1	44.1	44.5	44.6	
41	40.9	41	41.8	41.6	41.1	41.2	41.6	41.9	42.4	42.5	42.7	42.7	41	41	41.5	41.6	
38.9	38.9	39.1	40	39.7	39.3	39.4	39.9	40.2	40.8	41	41.2	41.2	39.5	39.5	40	40.1	
35.1	35.2	35.4	36.4	36.1	36.2	36.3	36.7	37	37.5	37.7	37.8	37.7	36.4	36.3	37	37.1	
33.1	33.2	33.5	34.7	34.4	34.8	34.5	35	35.2	35.7	35.9	35.9	35.6	34.4	34.4	35.2	35.3	
29.7	29.8	29.9	30.1	30.1	29.7	29.7	29.8	29.9	29.6	29.6	29.6	29.4	30.2	30.1	30.2	30.2	
31.5	7.9	3.3		1.2	37.8	108	289	463	830	883	804	829	0.9		0.6		
1.63E-06	1.63E-06	1.63E-06	1.37E-06	1.37E-06	1.57E-06	1.57E-06	1.6E-06	1.63E-06	1.6E-06	1.58E-06	1.55E-06	1.55E-06	1.63E-06	1.65E-06	1.6E-06	1.58E-06	
0.37	0.37	0.37	0.40	0.43	0.57	0.53	0.50	0.50	0.47	0.47	0.43	0.47	0.53	0.53	0.50	0.50	
0.69	0.70	0.69	0.69	0.70	0.76	0.74	0.70	0.69	0.64	0.64	0.61	0.61	0.67	0.67	0.64	0.64	
0.73	0.73	0.72	0.75	0.75	0.76	0.76	0.76	0.76	0.79	0.79	0.79	0.80	0.70	0.71	0.72	0.72	
0.77	0.77	0.79	0.90	0.86	0.93	0.94	0.99	1.01	1.13	1.16	1.17	1.19	0.89	0.89	0.97	0.99	
0.93	0.95	0.93	0.90	0.90	0.90	0.90	0.85	0.83	0.78	0.78	0.75	0.73	0.78	0.78	0.75	0.75	
0.53	0.50	0.48	0.45	0.48	0.45	0.45	0.43	0.42	0.40	0.38	0.38	0.38	0.38	0.38	0.38	0.38	
0.95	0.92	0.93	0.90	0.90	0.77	0.78	0.80	0.80	0.82	0.82	0.85	0.88	0.78	0.80	0.75	0.75	
0.50	0.50	0.48	0.42	0.43	0.35	0.45	0.43	0.45	0.45	0.45	0.48	0.53	0.50	0.48	0.45	0.45	
1.13	1.13	1.20	1.53	1.43	1.70	1.60	1.73	1.77	2.03	2.10	2.10	2.07	1.40	1.43	1.67	1.70	
												K (m/s)					
4.3E-04	4.3E-04	4.3E-04	3.3E-04	3.0E-04	2.7E-04	2.8E-04	3.1E-04	3.1E-04	3.3E-04	3.3E-04	3.4E-04	3.2E-04	2.9E-04	3.0E-04	3.1E-04	3.0E-04	
2.3E-04	2.2E-04	2.3E-04	1.9E-04	1.9E-04	2.0E-04	2.0E-04	2.2E-04	2.3E-04	2.4E-04	2.4E-04	2.4E-04	2.4E-04	2.3E-04	2.4E-04	2.4E-04	2.4E-04	
2.1E-04	2.2E-04	2.2E-04	1.8E-04	1.8E-04	2.0E-04	2.0E-04	2.0E-04	2.1E-04	2.0E-04	1.9E-04	1.9E-04	1.9E-04	2.2E-04	2.2E-04	2.1E-04	2.1E-04	
2.0E-04	2.0E-04	2.0E-04	1.5E-04	1.5E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.8E-04	1.8E-04	1.6E-04	1.5E-04	
1.7E-04	1.7E-04	1.7E-04	1.5E-04	1.5E-04	1.7E-04	1.7E-04	1.8E-04	1.9E-04	2.0E-04	2.0E-04	2.0E-04	2.1E-04	2.0E-04	2.0E-04	2.1E-04	2.0E-04	
3.0E-04	3.1E-04	3.3E-04	2.9E-04	2.8E-04	3.4E-04	3.4E-04	3.6E-04	3.7E-04	3.9E-04	4.1E-04	4.0E-04	4.0E-04	4.2E-04	4.2E-04	4.1E-04	4.1E-04	
1.7E-04	1.7E-04	1.7E-04	1.5E-04	1.5E-04	1.9E-04	1.9E-04	1.9E-04	2.0E-04	1.9E-04	1.8E-04	1.8E-04	1.7E-04	2.0E-04	2.0E-04	2.1E-04	2.0E-04	
3.1E-04	3.1E-04	3.3E-04	3.1E-04	3.1E-04	4.3E-04	3.4E-04	3.6E-04	3.5E-04	3.4E-04	3.4E-04	3.1E-04	2.8E-04	3.1E-04	3.3E-04	3.4E-04	3.4E-04	
1.4E-04	1.4E-04	1.3E-04	8.6E-05	9.2E-05	8.9E-05	9.4E-05	8.9E-05	8.9E-05	7.6E-05	7.3E-05	7.1E-05	7.2E-05	1.1E-04	1.1E-04	9.2E-05	9.0E-05	
0.77	0.76	0.77	0.65	0.63	0.67	0.68	0.74	0.77	0.81	0.80	0.82	0.82	0.79	0.80	0.81	0.80	
0.89	0.90	0.91	0.73	0.73	0.83	0.83	0.84	0.86	0.81	0.80	0.78	0.78	0.93	0.93	0.89	0.88	
0.96	0.96	0.95	0.69	0.73	0.77	0.76	0.74	0.73	0.65	0.62	0.60	0.60	0.84	0.85	0.75	0.73	
0.72	0.72	0.72	0.55	0.51	0.45	0.48	0.52	0.53	0.56	0.55	0.58	0.54	0.50	0.50	0.52	0.51	
0.74	0.72	0.74	0.64	0.64	0.73	0.73	0.79	0.83	0.86	0.86	0.87	0.90	0.88	0.89	0.89	0.88	
0.92	0.97	1.02	0.90	0.86	1.04	1.04	1.12	1.14	1.19	1.26	1.23	1.23	1.29	1.31	1.27	1.26	
0.93	0.95	0.95	0.82	0.82	1.09	1.09	1.08	1.10	1.05	1.04	0.99	0.96	1.14	1.11	1.15	1.14	
1.32	1.32	1.39	1.30	1.30	1.81	1.41	1.53	1.47	1.44	1.43	1.32	1.20	1.32	1.41	1.44	1.43	
0.78	0.78	0.74	0.48	0.52	0.50	0.53	0.50	0.50	0.43	0.41	0.40	0.41	0.63	0.62	0.52	0.50	

Constant HeadTest min ml s

Test P ml s min 38000

Date 12-Jul-07 Water Properties (T= 20C) 40280

Sand French Drain sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.5% (kaolinite)

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	4	8	12	17	26	35	53	75	98	116	155	201	264	328
Pore volumes								0	0.4	0.8	1.1	1.6	2.4	3.1	4.5	6.0	7.5	8.6	10.6	12.7	15.1	17.0
Volume collected (mL)		92	69	68	63	62	120		68	66	59	60	58	56	50	47	42	78	34	57	45	37
Time taken to collect (s)		60	60	60	60	60	30		60	60	60	60	60	60	60	60	60	120	60	120	120	120
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																						
Point 1 (cm)	1.5	49.35	50.25	50.25					50.5	50.6	50.8	51.0	51.2	51.4	51.8	52.1	52.4	52.7	53.0	53.3	53.6	53.8
Point 2 (cm)	3																					
Point 3 (cm)	4.5		49.3	49.4					49.5	49.7	49.9	50.1	50.3	50.5	50.9	51.3	51.6	51.8	52.4	52.6	52.9	53.2
Point 4 (cm)	8.5		43.9	44.4					44.4	44.4	44.5	44.6	44.6	44.7	44.7	44.8	44.8	44.8	44.8	44.9	45.5	45.9
Point 5 (cm)	12.5		41	41.6					41.6	41.5	41.6	41.6	41.5	41.5	41.4	41.1	41.0	40.9	40.9	41.0	42.3	43.0
Point 6 (cm)	16.5		44.6	34.9					34.9	34.7	34.6	34.6	34.3	34.1	33.8	33.5	33.3	33.0	32.7	32.2	32.0	32.1
Point 7 (cm)	20.5		32.3	32.55					32.5	32.5	32.5	32.5	32.3	32.1	31.9	31.8	31.6	31.5	31.3	31.0	30.8	30.9
Point 8 (cm)	22																					
Point 9 (cm)	23.5	29.3	29.35	29.35					29.3	29.3	29.3	29.2	29.1	29.1	29.0	29.0	28.9	28.9	28.7	28.7	28.5	28.5
			1.15		1.15E-06																	
			1000	mL/L			Turb.	0	17.0	43.0	78	102	139	179	196	220	221	221	192	253	299	326
Calculations			1000	L/m^3																		
Q (m3/s)		1.53E-06	1.15E-06	1.13E-06	1.05E-06	1.03E-06	0.000004		1.133E-06	0.0000011	9.833E-07	0.000001	9.667E-07	9.333E-07	8.3333E-07	7.8333E-07	0.0000007	0.00000065	5.6667E-07	4.75E-07	3.75E-07	3.08E-07
i (Point 1-3)		16.45	0.32	0.28	0.00	0.00	0.00		0.32	0.30	0.28	0.30	0.30	0.30	0.28	0.27	0.27	0.28	0.20	0.22	0.23	0.20
i (Point 1-4)		7.05	0.91	0.84	0.00	0.00	0.00		0.86	0.89	0.89	0.91	0.94	0.96	1.01	1.04	1.09	1.12	1.17	1.19	1.16	1.13
i (Point 1-9)		0.91	0.95	0.95	0.00	0.00	0.00		0.96	0.97	0.98	0.99	1.00	1.01	1.03	1.05	1.07	1.08	1.10	1.12	1.14	1.15
i (Point 6-9)		-4.19	2.18	0.79	0.00	0.00	0.00		0.80	0.78	0.76	0.77	0.74	0.71	0.69	0.65	0.64	0.59	0.57	0.51	0.50	0.51
i (Point 3-4)		0.00	1.35	1.25	0.00	0.00	0.00		1.28	1.33	1.35	1.36	1.43	1.45	1.55	1.63	1.70	1.75	1.90	1.93	1.85	1.83
i (Point 4-5)		0.00	0.73	0.70	0.00	0.00	0.00		0.70	0.73	0.73	0.75	0.78	0.80	0.83	0.92	0.95	0.98	0.98	0.98	0.80	0.73
i (Point 5-6)		0.00	-0.90	1.68	0.00	0.00	0.00		1.68	1.70	1.75	1.75	1.80	1.85	1.90	1.90	1.93	1.98	2.05	2.20	2.58	2.73
i (Point 6-7)		0.00	3.08	0.59	0.00	0.00	0.00		0.60	0.55	0.53	0.53	0.50	0.51	0.48	0.44	0.42	0.38	0.35	0.30	0.30	0.30
i (Point 7-9)		-9.77	0.98	1.07	0.00	0.00	0.00		1.07	1.08	1.08	1.10	1.07	0.98	0.97	0.93	0.92	0.88	0.87	0.78	0.77	0.80
K (m/s)																						
(Point 1-3)		9.0E-06	3.5E-04	3.9E-04	#DIV/0!	#DIV/0!	#DIV/0!		3.4E-04	3.5E-04	3.3E-04	3.2E-04	3.1E-04	3.0E-04	2.8E-04	2.8E-04	2.5E-04	2.2E-04	2.7E-04	2.1E-04	1.5E-04	1.5E-04
(Point 1-4)		2.1E-05	1.2E-04	1.3E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.3E-04	1.2E-04	1.1E-04	1.1E-04	9.9E-05	9.4E-05	8.0E-05	7.2E-05	6.2E-05	5.6E-05	4.7E-05	3.8E-05	3.1E-05	2.6E-05
(Point 1-9)		1.6E-04	1.2E-04	1.1E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.1E-04	1.1E-04	9.7E-05	9.7E-05	9.3E-05	8.9E-05	7.8E-05	7.2E-05	6.3E-05	5.8E-05	4.9E-05	4.1E-05	3.2E-05	2.6E-05
(Point 6-9)		-3.5E-05	5.1E-05	1.4E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.4E-04	1.4E-04	1.2E-04	1.2E-04	1.3E-04	1.3E-04	1.2E-04	1.2E-04	1.1E-04	1.1E-04	9.5E-05	9.0E-05	7.2E-05	5.8E-05
(Point 3-4)		#DIV/0!	8.2E-05	8.7E-05	#DIV/0!	#DIV/0!	#DIV/0!		8.6E-05	8.0E-05	7.0E-05	7.1E-05	6.5E-05	6.2E-05	5.2E-05	4.6E-05	4.0E-05	3.6E-05	2.9E-05	2.4E-05	2.0E-05	1.6E-05
(Point 4-5)		#DIV/0!	1.5E-04	1.6E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.6E-04	1.5E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	9.7E-05	8.2E-05	7.1E-05	6.4E-05	5.6E-05	4.7E-05	4.5E-05	4.1E-05
(Point 5-6)		#DIV/0!	-1.2E-04	6.5E-05	#DIV/0!	#DIV/0!	#DIV/0!		6.5E-05	6.2E-05	5.4E-05	5.5E-05	5.2E-05	4.9E-05	4.2E-05	4.0E-05	3.5E-05	3.2E-05	2.7E-05	2.1E-05	1.4E-05	1.1E-05
(Point 6-7)		#DIV/0!	3.6E-05	1.9E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.8E-04	1.9E-04	1.8E-04	1.8E-04	1.9E-04	1.8E-04	1.7E-04	1.7E-04	1.6E-04	1.7E-04	1.6E-04	1.5E-04	1.2E-04	9.9E-05
(Point 7-9)		-1.5E-05	1.1E-04	1.0E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.0E-04	9.8E-05	8.7E-05	8.8E-05	8.7E-05	9.1E-05	8.3E-05	8.1E-05	7.4E-05	7.1E-05	6.3E-05	5.8E-05	4.7E-05	3.7E-05
% of Ko (1-4)	Ko =					1.3E-04		1.00	0.97	0.92	0.81	0.81	0.76	0.72	0.61	0.55	0.48	0.43	0.36	0.29	0.24	0.20
% of Ko (1-9)	Ko =					1.1E-04		1.00	0.99	0.95	0.84	0.85	0.81	0.77	0.68	0.62	0.55	0.50	0.43	0.36	0.28	0.22
% of Ko (6-9)	Ko =					1.4E-04		1.00	0.99	0.99	0.90	0.91	0.91	0.91	0.85	0.84	0.77	0.77	0.69	0.66	0.52	0.42
% of Ko (1-3)	Ko =					3.9E-04		1.00	0.89	0.92	0.87	0.83	0.81	0.78	0.74	0.73	0.66	0.57	0.71	0.55	0.40	0.39
% of Ko (3-4)	Ko =					8.7E-05		1.00	0.98	0.92	0.80	0.81	0.75	0.71	0.59	0.53	0.45	0.41	0.33	0.27	0.22	0.19
% of Ko (4-5)	Ko =					1.6E-04		1.00	1.00	0.94	0.84	0.82	0.77	0.72	0.62	0.52	0.46	0.41	0.36	0.30	0.29	0.26
% of Ko (5-6)	Ko =					6.5E-05		1.00	1.00	0.96	0.83	0.84	0.79	0.75	0.65	0.61	0.54	0.49	0.41	0.32	0.22	0.17
% of Ko (6-7)	Ko =					1.9E-04		1.00	0.98	1.04	0.97	0.99	1.00	0.94	0.91	0.93	0.85	0.90	0.84	0.82	0.65	0.53
% of Ko (7-9)	Ko =					1.0E-04		1.00	1.00	0.96	0.85	0.86	0.85	0.89	0.81	0.79	0.72	0.69	0.62	0.57	0.46	0.36

Sample	Pre-wash	Post-wash	Fines	% Fines
P-1	1408.1	1343.2	64.9	4.6%
P-2	1089.8	1041.6	48.2	4.4%
P-3	1489.2	1403.4	85.8	5.8%

Post-test total mass of fines 199 g
Mass of fines injected 196 g

Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

65 L 349.4624

0.186 L/min 5.824373

1.06 196 grams 660

49500

	13.3	16.2	24.6	30.5	35.5	37.1	38.7	39.0	39.1
371	419	612	1358	2092	3046	3536	4276	4512	4605
18.1	19.3	23.5	35.7	44.2	51.5	53.8	56.2	56.7	56.8
36	33	27	18	14	7	6	3	2	6
120	120	120	120	120	120	120	120	120	300
15	15	15	15	15	15	15	15	15	15
53.8	53.8	53.8	53.8	53.1	46.5	46.8	42.3	40.5	39.9
53.2	53.2	53.2	51.9	48.0	38.8	36.0	33.5	33.0	32.7
45.5	46.6	47.1	43.3	39.4	33.1	31.9	30.8	30.5	32.4
43.1	44.7	45.6	42.1	33.2	30.3	30.0		29.4	29.3
32.3	32.7	35.6	36.7	31.9	30.0	29.8		29.1	29.0
31.0	31.3	33.1	34.7						
28.5	28.4	28.7	29.8	29.6	28.9	29.5	29.5	28.6	28.5
396	432	441	1100						
3E-07	2.75E-07	2.25E-07	1.5E-07	1.17E-07	5.83E-08	5E-08	2.5E-08	1.67E-08	2E-08
0.18	0.18	0.20	0.62	1.70	2.55	3.58	2.93	2.50	2.38
1.18	1.02	0.96	1.49	1.96	1.91	2.12	1.64	1.43	1.06
1.15	1.15	1.14	1.09	1.07	0.80	0.79	0.58	0.54	0.52
0.55	0.61	0.99	0.99	0.33	0.16	0.05	-4.21	0.08	0.08
1.93	1.65	1.53	2.15	2.15	1.43	1.03	0.68	0.63	0.08
0.60	0.48	0.38	0.30	1.55	0.70	0.48	7.70	0.28	0.77
2.70	3.00	2.50	1.35	0.33	0.08	0.05	0.00	0.07	0.08
0.32	0.35	0.64	0.50	7.98	7.50	7.45	0.00	7.28	7.25
0.85	0.97	1.47	1.65	-9.87	-9.63	-9.82	-9.82	-9.52	-9.48
1.6E-04	1.4E-04	1.1E-04	2.3E-05	6.6E-06	2.2E-06	1.3E-06	8.2E-07	6.4E-07	8.1E-07
2.5E-05	2.6E-05	2.3E-05	9.7E-06	5.7E-06	2.9E-06	2.3E-06	1.5E-06	1.1E-06	1.8E-06
2.5E-05	2.3E-05	1.9E-05	1.3E-05	1.1E-05	7.0E-06	6.1E-06	4.1E-06	3.0E-06	3.7E-06
5.3E-05	4.3E-05	2.2E-05	1.5E-05	3.4E-05	3.6E-05	9.6E-05	-5.7E-07	2.0E-05	2.5E-05
1.5E-05	1.6E-05	1.4E-05	6.7E-06	5.2E-06	3.9E-06	4.7E-06	3.6E-06	2.6E-06	2.6E-05
4.8E-05	5.6E-05	5.8E-05	4.8E-05	7.2E-06	8.0E-06	1.0E-05	3.1E-07	5.8E-06	2.5E-06
1.1E-05	8.8E-06	8.7E-06	1.1E-05	3.5E-05	7.5E-05	9.6E-05	#DIV/0!	2.1E-05	2.6E-05
8.9E-05	7.6E-05	3.4E-05	2.9E-05	1.4E-06	7.5E-07	6.5E-07	#DIV/0!	2.2E-07	2.7E-07
3.4E-05	2.7E-05	1.5E-05	8.8E-06	-1.1E-06	-5.8E-07	-4.9E-07	-2.5E-07	-1.7E-07	-2.0E-07
0.19	0.20	0.17	0.07	0.04	0.02	0.02	0.01	0.01	0.01
0.22	0.20	0.16	0.12	0.09	0.06	0.05	0.04	0.03	0.03
0.38	0.31	0.16	0.11						
0.41	0.38	0.28	0.06	0.02	0.01	0.00	0.00	0.00	0.00
0.17	0.18	0.16	0.08	0.06	0.05	0.05	0.04	0.03	0.29
0.31	0.36	0.37	0.31	0.05	0.05	0.07	0.00	0.04	0.02
0.16	0.14	0.13	0.16	0.53	1.15	1.48	#DIV/0!	0.33	0.39
0.48	0.41	0.18	0.16	0.01	0.00	0.00	#DIV/0!	0.00	0.00
0.33	0.27	0.14	0.09	-0.01	-0.01	0.00	0.00	0.00	0.00

French Drain Sand with Battleford Till fines

Constant HeadTest min ml s

Test AE 1st setup ml s min

Date 27-Aug-07 Water Properties (T= 20C)

Sand French Drain sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.5% (B Till) (5 g/L)

Time after beginning flow with suspension of fines (min)

		Elevation	Water	Water	Water	Water	Water		0	3	10	18	30	46	54	70	97	115	173	227	420	450
Pore volumes									0	0.6	1.8	3.3	5.4	8.0	9.3	11.7	15.6	18.0	25.5	31.7	50.9	53.6
Volume collected (mL)			128	128	126	126	127			127	127	121	117	110	107	101	98	91	85	75	62	61
Time taken to collect (s)			60	60	60	60	60			60	60	60	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)			15	15	15	15	15			15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings					55			55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	44.15	44.45	44.5	44.45	44.3			44.3	45.0	45.5	45.9	46.5	46.7	47.2	47.6	48.0	48.6	49.3	50.3	50.4
Point 3 (cm)	4.5	7.2	42.7	43	43.15	43.1	43			43.3	43.5	43.8	44.2	44.6	44.7	45.0	45.4	45.8	46.1	46.6	47.2	47.2
Point 4 (cm)	8.5	11.2	40.8	41.3	41.5	41.6	41.6			42.0	42.1	42.4	42.8	43.2	43.3	43.7	44.1	44.4	44.8	45.3	46.0	46.0
Point 5 (cm)	12.5	15.2	37.5	38	38.3	38.6	38.8			39.2	39.3	39.5	39.8	40.1	40.2	40.5	41.0	41.3	41.8	42.3	43.3	43.3
Point 6 (cm)	16.5	19.2	32.55	32.8	33.15	33.45	33.9			34.1	34.1	34.2	34.3	34.6	34.6	34.8	35.1	35.3	35.7	36.2	37.7	37.7
Point 7 (cm)	20.5	23.2	29.7	29.8	30	30.1	30.4			30.5	30.5	30.5	30.5	30.5	30.4	30.5	30.5	30.5	30.8	31.0	31.6	31.6
Point 9 (cm)	23.5	26.2	28.5	28.6	28.7	28.7	28.8			28.9	28.9	28.8	28.8	28.8	28.7	28.8	28.8	28.8	28.8	29.1	29.3	29.1
	25			2.133333		2.13E-06	28			28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L			Turb.	0	182.0	206.0	227	261	269	306	314	319	379	400	421	504	609
Calculations				1000	L/m^3																	
Q (m3/s)			2.13E-06	2.13E-06	2.1E-06	2.1E-06	2.12E-06			2.117E-06	2.117E-06	2.017E-06	1.95E-06	1.833E-06	1.783E-06	1.6833E-06	1.6333E-06	1.5167E-06	1.4167E-06	1.25E-06	1.03E-06	1.02E-06
i (Point 1-3)			0.48	0.48	0.45	0.45	0.43			0.33	0.50	0.57	0.57	0.63	0.67	0.72	0.73	0.73	0.82	0.90	1.03	1.07
i (Point 1-4)			0.48	0.45	0.43	0.41	0.39			0.33	0.41	0.44	0.45	0.48	0.49	0.50	0.50	0.51	0.54	0.57	0.62	0.63
i (Point 1-9)			0.71	0.72	0.72	0.72	0.70			0.70	0.73	0.76	0.78	0.80	0.82	0.83	0.85	0.87	0.90	0.92	0.95	0.97
i (Point 6-9)			0.58	0.60	0.64	0.68	0.73			0.75	0.75	0.77	0.79	0.83	0.84	0.85	0.90	0.93	0.99	1.01	1.19	1.23
i (Point 3-4)			0.48	0.43	0.41	0.38	0.35			0.32	0.35	0.35	0.36	0.36	0.35	0.34	0.32	0.35	0.33	0.33	0.31	0.30
i (Point 4-5)			0.82	0.82	0.80	0.75	0.70			0.70	0.70	0.73	0.75	0.76	0.77	0.79	0.78	0.78	0.75	0.75	0.66	0.68
i (Point 5-6)			1.24	1.30	1.29	1.29	1.23			1.28	1.30	1.33	1.36	1.38	1.40	1.44	1.48	1.50	1.53	1.53	1.41	1.40
i (Point 6-7)			0.71	0.75	0.79	0.84	0.88			0.90	0.90	0.93	0.95	1.03	1.05	1.06	1.15	1.20	1.23	1.30	1.51	1.53
i (Point 7-9)			0.40	0.40	0.43	0.47	0.53			0.55	0.55	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.67	0.63	0.77	0.83
K (m/s)																						
(Point 1-3)			4.2E-04	4.2E-04	4.5E-04	4.5E-04	4.7E-04			6.1E-04	4.1E-04	3.4E-04	3.3E-04	2.8E-04	2.6E-04	2.3E-04	2.1E-04	2.0E-04	1.7E-04	1.3E-04	9.6E-05	9.2E-05
(Point 1-4)			4.3E-04	4.6E-04	4.7E-04	5.0E-04	5.3E-04			6.2E-04	4.9E-04	4.4E-04	4.2E-04	3.7E-04	3.5E-04	3.2E-04	3.1E-04	2.8E-04	2.5E-04	2.1E-04	1.6E-04	1.6E-04
(Point 1-9)			2.9E-04	2.9E-04	2.8E-04	2.8E-04	2.9E-04			2.9E-04	2.8E-04	2.6E-04	2.4E-04	2.2E-04	2.1E-04	1.9E-04	1.8E-04	1.7E-04	1.5E-04	1.3E-04	1.0E-04	1.0E-04
(Point 6-9)			3.5E-04	3.4E-04	3.2E-04	3.0E-04	2.8E-04			2.7E-04	2.7E-04	2.5E-04	2.4E-04	2.1E-04	2.0E-04	1.9E-04	1.7E-04	1.6E-04	1.4E-04	1.2E-04	8.3E-05	8.0E-05
(Point 3-4)			4.3E-04	4.8E-04	4.9E-04	5.4E-04	5.8E-04			6.3E-04	5.8E-04	5.5E-04	5.2E-04	4.9E-04	4.9E-04	4.8E-04	4.8E-04	4.2E-04	4.2E-04	3.7E-04	3.2E-04	3.3E-04
(Point 4-5)			2.5E-04	2.5E-04	2.5E-04	2.7E-04	2.9E-04			2.9E-04	2.9E-04	2.7E-04	2.5E-04	2.3E-04	2.2E-04	2.1E-04	2.0E-04	1.9E-04	1.8E-04	1.6E-04	1.5E-04	1.5E-04
(Point 5-6)			1.7E-04	1.6E-04	1.6E-04	1.6E-04	1.7E-04			1.6E-04	1.6E-04	1.5E-04	1.4E-04	1.3E-04	1.2E-04	1.1E-04	1.1E-04	9.7E-05	8.9E-05	7.9E-05	7.0E-05	7.0E-05
(Point 6-7)			2.9E-04	2.7E-04	2.6E-04	2.4E-04	2.3E-04			2.3E-04	2.3E-04	2.1E-04	2.0E-04	1.7E-04	1.6E-04	1.5E-04	1.4E-04	1.2E-04	1.1E-04	9.3E-05	6.6E-05	6.4E-05
(Point 7-9)			5.1E-04	5.1E-04	4.7E-04	4.3E-04	3.8E-04			3.7E-04	3.7E-04	3.4E-04	3.3E-04	3.1E-04	3.0E-04	2.9E-04	2.8E-04	2.6E-04	2.0E-04	1.9E-04	1.3E-04	1.2E-04

% of Ko (1-4)	Ko =	5.3E-04	1.00	1.17	0.93	0.83	0.79	0.70	0.67	0.61	0.60	0.54	0.48	0.40	0.30	0.29
% of Ko (1-9)	Ko =	2.9E-04	1.00	1.00	0.96	0.88	0.84	0.76	0.73	0.67	0.64	0.58	0.53	0.45	0.36	0.35
% of Ko (6-9)	Ko =	2.8E-04	1.00	0.97	0.97	0.90	0.85	0.76	0.73	0.68	0.62	0.56	0.49	0.42	0.30	0.28
% of Ko (1-3)	Ko =	4.7E-04	1.00	1.30	0.87	0.73	0.70	0.59	0.55	0.48	0.46	0.42	0.36	0.28	0.20	0.20
% of Ko (3-4)	Ko =	5.8E-04	1.00	1.08	1.00	0.95	0.89	0.84	0.84	0.82	0.83	0.72	0.72	0.64	0.55	0.56
% of Ko (4-5)	Ko =	2.9E-04	1.00	1.00	1.00	0.92	0.86	0.80	0.76	0.71	0.70	0.65	0.62	0.55	0.52	0.50
% of Ko (5-6)	Ko =	1.7E-04	1.00	0.96	0.94	0.88	0.83	0.77	0.74	0.68	0.64	0.59	0.54	0.47	0.42	0.42
% of Ko (6-7)	Ko =	2.3E-04	1.00	0.97	0.97	0.90	0.85	0.74	0.70	0.65	0.59	0.52	0.48	0.40	0.28	0.28
% of Ko (7-9)	Ko =	3.8E-04	1.00	0.97	0.97	0.90	0.87	0.82	0.79	0.75	0.73	0.67	0.54	0.50	0.34	0.31

								37A	16A	27A	Z2	28A
Sample	Tare	Pre-wash	Post-wash	Fines	% Fines		Tare	14.06	14.1	14.33	14.3	14.26
AE-1	89.90	704.13	681.21	22.92	3.7%	3	Volume	19.60	19.6	18.6	19.1	18.7
AE-2	85.92	817.07	792.21	24.86	3.4%	2	Mass After	14.11	14.12	14.36	14.33	14.28
AE-3	78.10	669.33	649.15	20.18	3.4%	5	g solids	0.05	0.02	0.03	0.03	0.02
AE-4	86.21	784.44	760.18	24.26	3.5%	4	g salt					
AE-5	90.60	725.15	701.79	23.36	3.7%	6	g clay	0.05	0.02	0.03	0.03	0.02
AE-6	81.04	741.74	706.63	35.11	5.3%	1	clay (g/L)	2.55	1.02	1.61	1.57	1.07
	511.77	4441.86	4291.17	150.69	3.8%							

Post-test total mass of fines 151 g

Mass of fines injected 519 g

0.035116 Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

38000	1.06							519	g
40280									
	83.7	86.9	89.5	94.2	97.7	100.5	102.6	104	L

1170	1224	1278	1326	1416	1487	1547	1594	1624
116.9	121.6	126.2	130.0	136.8	141.9	146.0	149.0	150.9
60	60	57	54	50	48	46	43	42
60	60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15	15
55	55	55	55	55	55	55	55	55
50.8	51.2	51.4	51.5	51.7	51.8	52.0	52.0	52.0
43.7	42.9	42.4	41.8	41.0	40.5	39.9	39.5	39.2
42.5	41.7	41.2	40.6	40.2	39.6	39.1	38.6	38.4
40.1	39.5	39.0	38.5	37.9	37.3	36.9	36.5	36.2
35.9	35.5	35.3	34.8	34.3	33.8	33.5	33.1	32.8
30.8	30.6	30.7	30.5	30.3	30.1	29.9	29.7	29.6
28.6	28.6	28.7	28.6	28.5	28.5	28.4	28.3	28.2
28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
745	982	952	907	888	878	954.0	951	1100

0.000001	0.000001	9.5E-07	9E-07	8.33E-07	8E-07	7.67E-07	7.17E-07	7E-07
2.37	2.75	3.00	3.23	3.57	3.77	4.03	4.17	4.27
1.19	1.36	1.46	1.56	1.64	1.74	1.85	1.91	1.94
1.01	1.03	1.03	1.04	1.05	1.06	1.07	1.08	1.08
1.04	0.99	0.94	0.88	0.83	0.76	0.73	0.69	0.66
0.30	0.31	0.30	0.31	0.20	0.23	0.21	0.23	0.20
0.60	0.54	0.55	0.52	0.58	0.58	0.54	0.53	0.55
1.06	1.00	0.93	0.93	0.90	0.88	0.85	0.85	0.85
1.26	1.23	1.16	1.06	1.01	0.92	0.90	0.85	0.80
0.73	0.67	0.65	0.63	0.58	0.53	0.50	0.47	0.47

4.1E-05	3.5E-05	3.0E-05	2.7E-05	2.2E-05	2.0E-05	1.8E-05	1.7E-05	1.6E-05
8.1E-05	7.1E-05	6.3E-05	5.5E-05	4.9E-05	4.4E-05	4.0E-05	3.6E-05	3.5E-05
9.5E-05	9.4E-05	8.9E-05	8.3E-05	7.6E-05	7.3E-05	6.9E-05	6.4E-05	6.2E-05
9.3E-05	9.8E-05	9.7E-05	9.9E-05	9.7E-05	1.0E-04	1.0E-04	1.0E-04	1.0E-04
3.2E-04	3.1E-04	3.0E-04	2.8E-04	4.0E-04	3.4E-04	3.5E-04	3.1E-04	3.4E-04
1.6E-04	1.8E-04	1.7E-04	1.7E-04	1.4E-04	1.3E-04	1.4E-04	1.3E-04	1.2E-04
9.1E-05	9.6E-05	9.9E-05	9.4E-05	8.9E-05	8.8E-05	8.7E-05	8.1E-05	7.9E-05
7.6E-05	7.9E-05	7.9E-05	8.2E-05	7.9E-05	8.3E-05	8.2E-05	8.1E-05	8.4E-05
1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.5E-04	1.4E-04

0.15	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.07
0.33	0.32	0.31	0.29	0.26	0.25	0.24	0.22	0.22
0.33	0.35	0.35	0.35	0.35	0.36	0.36	0.36	0.37
0.09	0.07	0.06	0.06	0.05	0.04	0.04	0.04	0.03
0.55	0.53	0.52	0.48	0.69	0.59	0.60	0.53	0.58
0.55	0.62	0.57	0.57	0.48	0.46	0.47	0.45	0.42
0.54	0.58	0.59	0.56	0.54	0.53	0.52	0.49	0.48
0.33	0.34	0.34	0.35	0.34	0.36	0.35	0.35	0.36
0.34	0.38	0.37	0.36	0.36	0.38	0.39	0.39	0.38

41A	72A	36A	Z4
14.53	14.06	14.55	14.38
19.2	18.9	19.2	19.7
14.55	14.08	14.56	14.4
0.02	0.02	0.01	0.02
0.02	0.02	0.01	0.02
1.04	1.06	0.52	1.02

Constant HeadTest min ml s

Test Q ml s min 38000

Date 16-Jul-07 Water Properties (T= 20C) 40280

Sand French Drain sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.5% (Battleford Till fines) 5 g/L

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2	5	9	15	24	38	60	152	359	602	790	943	1081	1154
Pore volumes									0	0.2	0.5	0.9	1.4	2.2	3.3	5.0	11.2	22.4	32.9	39.4	43.9	47.4	48.7
Volume collected (mL)			116	92	68	68	62	120		68	65	61	60	88	82	78	80	69	51	43	39	30	22
Time taken to collect (s)			60	60	60	60	60	30		60	60	60	60	90	90	90	120	120	120	120	120	120	120
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings				55				55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	1.5	45.7	47.6	49.05	49.05				49.4	49.5	49.2	49.3	49.3	49.5	49.8	50.6	51.6	51.7	51.7	51.8	51.4	49.7
Point 3 (cm)	4.5	4.5	41.9	42.1	43.7	43.7				43.8	43.7	43.2	43.1	42.9	42.7	42.4	42.0	44.3	44.8	45.5	42.8	38.5	36.7
Point 4 (cm)	8.5	8.5	38.9	39.3	39.9	40				40.1	39.9	39.6	39.4	39.3	39.6	38.8	38.6	39.2	40.6	41.6	41.2	38.5	34.3
Point 5 (cm)	12.5	12.5	37.1	37.5	38.1	38.2				38.2	38.1	37.8	37.7	37.6	37.5	37.4	36.7	37.6	38.5	38.8	38.9	36.5	34.0
Point 6 (cm)	16.5	16.5	33.5	33.6	34.1	34.1				34.1	34.1	33.8	33.8	33.7	33.6	33.4	32.8	33.0	33.6	35.5	36.2	34.4	31.0
Point 7 (cm)	20.5	20.5	30.4	30.3	30.4	30.4				30.4	30.4	30.3	30.2	30.1	30.1	30.1	29.9	29.8	30.1	30.8	30.9	30.1	29.7
Point 9 (cm)	23.5	23.5	29.4	29.2	29.15	29.1				29.1	29.1	29.1	29.1	29.0	29.0	29.0	28.8	28.6	28.6	28.7	28.8	28.7	28.6
	25			1.533333		28				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L	1.53E-06		Turb.	0	2.0	4.1	4.0	4.5		9.1	15.0	27	131	332	752	987	977	1100
Calculations				1000	L/m^3																		
Q (m3/s)			1.93E-06	1.53E-06	1.13E-06	1.13E-06	1.03E-06	0.000004		1.133E-06	1.083E-06	1.017E-06	0.000001	9.778E-07	9.111E-07	8.6667E-07	6.6667E-07	5.75E-07	4.25E-07	3.58E-07	3.25E-07	2.5E-07	1.83E-07
i (Point 1-3)			1.27	1.83	1.78	1.78	0.00	0.00		1.87	1.92	2.00	2.05	2.13	2.25	2.45	2.87	2.43	2.28	2.07	2.98	4.28	4.32
i (Point 1-4)			0.97	1.19	1.31	1.29	0.00	0.00		1.33	1.36	1.37	1.41	1.43	1.41	1.56	1.71	1.77	1.58	1.44	1.51	1.84	2.19
i (Point 1-9)			0.74	0.84	0.90	0.91	0.00	0.00		0.92	0.93	0.92	0.92	0.92	0.93	0.95	0.99	1.05	1.05	1.05	1.05	1.03	0.96
i (Point 6-9)			0.59	0.63	0.71	0.71	0.00	0.00		0.71	0.71	0.68	0.68	0.67	0.66	0.64	0.57	0.63	0.71	0.97	1.06	0.82	0.35
i (Point 3-6)			0.70	0.71	0.80	0.80	0.00	0.00		0.81	0.80	0.78	0.78	0.77	0.76	0.75	0.77	0.94	0.93	0.83	0.55	0.34	0.48
i (Point 4-7)			0.71	0.75	0.79	0.80	0.00	0.00		0.81	0.79	0.78	0.77	0.77	0.79	0.73	0.73	0.78	0.88	0.90	0.86	0.70	0.38
K (m/s)																							
(Point 1-3)			1.5E-04	8.1E-05	6.1E-05	6.1E-05	#DIV/0!	#DIV/0!		5.8E-05	5.4E-05	4.9E-05	4.7E-05	4.4E-05	3.9E-05	3.4E-05	2.2E-05	2.3E-05	1.8E-05	1.7E-05	1.0E-05	5.6E-06	4.1E-06
(Point 1-4)			1.9E-04	1.2E-04	8.3E-05	8.4E-05	#DIV/0!	#DIV/0!		8.2E-05	7.6E-05	7.1E-05	6.8E-05	6.6E-05	6.2E-05	5.3E-05	3.7E-05	3.1E-05	2.6E-05	2.4E-05	2.1E-05	1.3E-05	8.0E-06
(Point 1-9)			2.5E-04	1.8E-04	1.2E-04	1.2E-04	#DIV/0!	#DIV/0!		1.2E-04	1.1E-04	1.1E-04	1.0E-04	1.0E-04	9.4E-05	8.8E-05	6.5E-05	5.3E-05	3.9E-05	3.3E-05	3.0E-05	2.3E-05	1.8E-05
(Point 6-9)			3.2E-04	2.3E-04	1.5E-04	1.5E-04	#DIV/0!	#DIV/0!		1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.1E-04	8.8E-05	5.7E-05	3.6E-05	2.9E-05	2.9E-05	5.0E-05
(Point 3-6)			2.7E-04	2.1E-04	1.4E-04	1.4E-04	#DIV/0!	#DIV/0!		1.3E-04	1.3E-04	1.2E-04	1.2E-04	1.2E-04	1.2E-04	1.1E-04	8.4E-05	5.9E-05	4.4E-05	4.1E-05	5.7E-05	7.0E-05	3.7E-05
(Point 4-7)			2.6E-04	2.0E-04	1.4E-04	1.4E-04	#DIV/0!	#DIV/0!		1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	1.2E-04	8.9E-05	7.1E-05	4.7E-05	3.8E-05	3.6E-05	3.4E-05	4.6E-05
% of Ko (1-3)		Ko =																					
% of Ko (1-4)		Ko =					8.4E-05		1.00	0.97	0.91	0.85	0.81	0.78	0.74	0.63	0.44	0.37	0.31	0.28	0.25	0.16	0.10
% of Ko (1-9)		Ko =					1.2E-04		1.00	0.98	0.94	0.89	0.87	0.85	0.78	0.73	0.54	0.44	0.32	0.27	0.25	0.19	0.15
% of Ko (6-9)		Ko =					1.5E-04		1.00	1.00	0.96	0.94	0.93	0.92	0.87	0.86	0.74	0.58	0.38	0.23	0.19	0.19	0.33

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines
Q-1		1348.70	1288.44	60.26	4.5%
Q-2		1092.90	1037.69	55.21	5.1%
Q-3		1488.90	1409.66	79.24	5.3%
		3930.50	3735.79	194.71	5.0%
			Post-test total mass of fines	195	g
			Mass of fines injected	187	g

0.052 Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

1.06			187	grams
	35.6	36.9	37.3	

1284	1433	1828	2170
50.4	51.7	53.6	54.2
14	10	3	4
120	120	120	300
15	15	15	15
55	55	55	55
50.0	44.1	35.8	32.7
34.7	33.1	31.4	30.1
32.6	31.4	30.3	29.5
33.1	31.7	29.7	29.2
29.9	29.5	29.2	28.9
29.3	29.3	29.2	28.8
28.6	28.7	28.8	28.7
28.0	28.0	28.0	28.0
		1100	219

1.17E-07	8.33E-08	2.5E-08	1.33E-08
5.10	3.67	1.47	0.85
2.49	1.81	0.79	0.45
0.97	0.70	0.32	0.18
0.19	0.11	0.06	0.03
0.40	0.30	0.18	0.10
0.28	0.18	0.09	0.06

2.2E-06	2.2E-06	1.6E-06	1.5E-06
4.5E-06	4.4E-06	3.1E-06	2.9E-06
1.2E-05	1.1E-05	7.5E-06	7.1E-06
6.0E-05	7.0E-05	3.7E-05	4.5E-05
2.8E-05	2.7E-05	1.3E-05	1.3E-05
4.1E-05	4.6E-05	2.6E-05	2.2E-05

0.05	0.05	0.04	0.03
0.10	0.10	0.06	0.06
0.40	0.46	0.25	0.29

Constant HeadTest

	Test AG	3rd setup			min	ml	s
					ml	s	min
Date	29-Aug-07				Water Properties (T= 20C)		
Sand	French Drain sand		A (m2)	0.01039	γ (kN/m3)	9.7866 μ (Ns/m2)	9.8E-04
Clay in suspension	0.1% Batt. Till	1 g/L					

38000 1.06
40280
20.5

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine			0	4	14	24	32	42	52	63	95	114	154	179	210	256	287	332
Pore volumes									0	0.4	1.5	2.6	3.4	4.4	5.4	6.5	9.5	11.3	14.9	17.1	19.8	23.6	26.2	29.8
Volume collected (mL)			91	82.5	80	78				75	74	72	71	69	68	66	65	64	61	60	58	57	56	56
Time taken to collect (s)			60	60	60	60				60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)			15	15	15	15				15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	55				55				55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	48.4	49	49.1	49.3				49.5	49.6	49.7	49.8	49.9	50.0	50.1	50.4	50.5	50.7	50.9	51.0	51.1	51.2	51.3
Point 3 (cm)	4.5	7.2				47.5				47.5	47.6	47.7	47.8	47.9	47.9	48.0	48.2	48.3	48.6	48.9	49.1	49.4	49.5	49.7
Point 4 (cm)	8.5	11.2	44.3	44.75	44.9	45				45.0	45.0	45.1	45.1	45.2	45.3	45.3	45.5	45.6	45.9	46.2	46.4	46.8	47.2	47.3
Point 5 (cm)	12.5	15.2				40.2				40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.3	40.5	40.5	40.8	41.1	41.1
Point 6 (cm)	16.5	19.2	32.85	32.9	32.85	32.8				32.7	32.6	32.5	32.4	32.4	32.3	32.3	32.2	32.2	32.1	32.1	32.2	32.1	32.2	32.3
Point 7 (cm)	20.5	23.2				28.7				28.7	28.6	28.6	28.6	28.6	28.5	28.5	28.5	28.4	28.4	28.4	28.4	28.4	28.4	28.4
Point 9 (cm)	23.5	26.2	28.2	28.2	28.1	28.1				28.1	28.1	28.1	28.0	28.0	28.0	28.0	28.0	27.9	27.9	27.9	27.9	28.5	28.4	28.4
	25			1.375		28				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000 mL/L		1.38E-06		Turb.	0	9.3	2.7	3.0	3.0	3.7	3.1	3.5	3.0	3.0	3.1	2.9	4.3	3.5	4.2	5.7
Calculations				1000 L/m^3																				
Q (m3/s)			1.52E-06	1.38E-06	1.33E-06	1.3E-06				1.25E-06	1.233E-06	0.0000012	1.183E-06	1.15E-06	1.133E-06	0.0000011	1.083E-06	1.067E-06	1.02E-06	0.000001	9.67E-07	9.5E-07	9.33E-07	9.33E-07
i (Point 1-3)			16.13	16.33	16.37	0.60				0.67	0.67	0.67	0.67	0.68	0.70	0.70	0.73	0.73	0.70	0.67	0.63	0.57	0.55	0.55
i (Point 1-4)			0.59	0.61	0.60	0.61				0.64	0.66	0.66	0.67	0.67	0.68	0.69	0.70	0.70	0.69	0.67	0.66	0.61	0.57	0.57
i (Point 1-9)			0.92	0.95	0.95	0.96				0.97	0.98	0.98	0.99	1.00	1.00	1.00	1.02	1.03	1.04	1.05	1.05	1.03	1.03	1.04
i (Point 6-9)			0.66	0.67	0.68	0.67				0.66	0.64	0.63	0.63	0.63	0.61	0.61	0.60	0.61	0.60	0.60	0.62	0.52	0.54	0.56
i (Point 3-4)			-11.08	-11.19	-11.23	0.63				0.63	0.65	0.65	0.67	0.66	0.66	0.68	0.68	0.67	0.68	0.67	0.68	0.65	0.59	0.59
i (Point 4-5)			11.08	11.19	11.23	1.20				1.20	1.20	1.23	1.23	1.25	1.26	1.28	1.33	1.35	1.40	1.44	1.48	1.50	1.51	1.55
i (Point 5-6)			-8.21	-8.23	-8.21	1.85				1.88	1.90	1.93	1.95	1.95	1.98	1.98	2.00	2.00	2.05	2.09	2.08	2.18	2.23	2.20
i (Point 6-7)			8.21	8.23	8.21	1.03				1.00	1.00	0.98	0.95	0.95	0.95	0.95	0.93	0.95	0.93	0.93	0.95	0.93	0.95	0.98
i (Point 7-9)			-9.40	-9.40	-9.37	0.20				0.20	0.17	0.17	0.20	0.20	0.17	0.17	0.17	0.17	0.17	0.17	0.18	-0.02	0.00	0.00
K (m/s)																								
(Point 1-3)			9.1E-06	8.1E-06	7.8E-06	2.1E-04				1.8E-04	1.8E-04	1.7E-04	1.7E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.6E-04	1.6E-04	1.6E-04
(Point 1-4)			2.5E-04	2.2E-04	2.1E-04	2.0E-04				1.9E-04	1.8E-04	1.8E-04	1.7E-04	1.6E-04	1.6E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.6E-04	1.6E-04
(Point 1-9)			1.6E-04	1.4E-04	1.3E-04	1.3E-04				1.2E-04	1.2E-04	1.2E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.0E-04	1.0E-04	9.4E-05	9.2E-05	8.8E-05	8.9E-05	8.7E-05	8.6E-05
(Point 6-9)			2.2E-04	2.0E-04	1.9E-04	1.9E-04				1.8E-04	1.8E-04	1.8E-04	1.8E-04	1.8E-04	1.8E-04	1.7E-04	1.7E-04	1.7E-04	1.6E-04	1.6E-04	1.5E-04	1.8E-04	1.7E-04	1.6E-04
(Point 3-4)			-1.3E-05	-1.2E-05	-1.1E-05	2.0E-04				1.9E-04	1.8E-04	1.8E-04	1.7E-04	1.7E-04	1.6E-04	1.6E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.5E-04
(Point 4-5)			1.3E-05	1.2E-05	1.1E-05	1.0E-04				1.0E-04	9.9E-05	9.4E-05	9.3E-05	8.9E-05	8.6E-05	8.3E-05	7.9E-05	7.6E-05	7.0E-05	6.7E-05	6.3E-05	6.1E-05	5.9E-05	5.8E-05
(Point 5-6)			-1.8E-05	-1.6E-05	-1.6E-05	6.8E-05				6.4E-05	6.2E-05	6.0E-05	5.8E-05	5.7E-05	5.5E-05	5.4E-05	5.2E-05	5.1E-05	4.8E-05	4.6E-05	4.5E-05	4.2E-05	4.0E-05	4.1E-05
(Point 6-7)			1.8E-05	1.6E-05	1.6E-05	1.2E-04				1.2E-04	1.2E-04	1.2E-04	1.2E-04	1.2E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.1E-04	1.0E-04	9.8E-05	9.9E-05	9.5E-05	9.2E-05
(Point 7-9)			-1.6E-05	-1.4E-05	-1.4E-05	6.3E-04				6.0E-04	7.1E-04	6.9E-04	5.7E-04	5.5E-04	6.5E-04	6.4E-04	6.3E-04	6.2E-04	5.9E-04	5.8E-04	5.1E-04	-5.5E-03	#DIV/0!	#DIV/0!

% of Ko (1-4)	Ko =	2.0E-04	1.00	0.92	0.89	0.86	0.83	0.81	0.79	0.76	0.73	0.72	0.70	0.70	0.70	0.73	0.77	0.77
% of Ko (1-9)	Ko =	1.3E-04	1.00	0.95	0.94	0.91	0.89	0.86	0.84	0.81	0.79	0.77	0.73	0.71	0.68	0.68	0.67	0.66
% of Ko (6-9)	Ko =	1.9E-04	1.00	0.98	0.99	0.99	0.97	0.94	0.95	0.92	0.93	0.90	0.88	0.86	0.80	0.94	0.89	0.87
% of Ko (1-3)	Ko =	2.1E-04	1.00	0.87	0.85	0.83	0.82	0.78	0.75	0.73	0.68	0.67	0.67	0.69	0.70	0.77	0.78	0.78
% of Ko (3-4)	Ko =	2.0E-04	1.00	0.96	0.91	0.89	0.84	0.83	0.82	0.78	0.77	0.76	0.72	0.71	0.69	0.70	0.76	0.76
% of Ko (4-5)	Ko =	1.0E-04	1.00	0.96	0.95	0.90	0.89	0.85	0.83	0.80	0.75	0.73	0.67	0.64	0.60	0.58	0.57	0.56
% of Ko (5-6)	Ko =	6.8E-05	1.00	0.95	0.92	0.89	0.86	0.84	0.82	0.79	0.77	0.76	0.71	0.68	0.66	0.62	0.60	0.60
% of Ko (6-7)	Ko =	1.2E-04	1.00	0.99	0.97	0.97	0.98	0.95	0.94	0.91	0.92	0.89	0.87	0.85	0.80	0.81	0.77	0.75
% of Ko (7-9)	Ko =	6.3E-04	1.00	0.96	1.14	1.11	0.91	0.88	1.05	1.02	1.00	0.98	0.94	0.92	0.81	-8.77	#DIV/0!	#DIV/0!

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
AG-1	84.31	811.99	782.27	29.72	4.1%	2
AG-2	108.29	687.96	666.32	21.64	3.7%	6
AG-3	85.10	672.22	650.12	22.10	3.8%	2
AG-4	95.12	767.36	743.72	23.64	3.5%	1
AG-5	85.90	656.10	637.23	18.87	3.3%	5
AG-6	81.84	845.87	823.28	22.59	3.0%	4
	540.6	4441.5	4302.9	138.6	3.6%	
	Post-test total mass of fines			139 g		
	Mass of fines injected			134 g		

3.6E-02 Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

3900.9 3762.4

25 L 75.8

													134 g
28.9	75.6	79.8	83.3	85.4	87.5	90.0	98.8	123.0	126.9	128.8	130.9	133.0	134 L
488	1461	1556	1637	1684	1734	1794	2016	2730	2867	2938	3020	3100	3126
42.0	109.8	115.9	121.0	124.0	127.1	130.7	143.4	178.7	184.3	187.1	190.2	193.2	194.2
51	45	44	43	43	42	41	38	30	27	26	26	26	26
60	60	60	60	60	60	60	60	60	60	60	60	60	60
15	15	15	15	15	15	15	15	15	15	15	15	15	15
55	55	55	55	55	55	55	55	55	55	55	55	55	55
51.6	51.2	51.2	51.1	51.0	51.0	51.2	50.9	49.5	49.5	49.4	49.5	49.2	49.2
50.1	49.5	49.6	49.4	49.4	49.4	49.5	49.0	47.5	47.5	47.5	47.6	47.3	47.3
47.9	47.5	47.5	47.4	47.3	47.3	47.4	46.9	45.4	45.5	45.5	45.6	45.5	45.5
41.5	43.0	43.0	42.8	42.8	42.7	42.8	41.9	39.5	39.6	39.7	39.7	39.4	39.4
32.4	35.1	35.1	34.5	34.3	34.2	34.3	32.7	31.4	31.1	31.1	31.1	31.0	31.0
28.3	28.9	29.0	28.8	28.8	28.5	28.5	28.3	28.4	28.3	28.3	28.3	28.2	28.2
28.4	28.2	28.2	28.4	28.4	27.5	27.5	27.7	27.7	27.6	27.6	27.6	27.5	27.5
28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
5.9	20.6	17.6	25.5	33.4	32.6	28.4	27.6	18.7	25.1	24.8	39.7	16.5	21.3

8.5E-07	7.5E-07	7.33E-07	7.17E-07	7.1667E-07	0.0000007	6.8333E-07	6.3333E-07	0.0000005	0.00000045	4.3333E-07	4.3333E-07	4.3333E-07	4.3333E-07
0.50	0.57	0.53	0.57	0.53	0.53	0.57	0.63	0.67	0.67	0.63	0.63	0.63	0.62
0.53	0.54	0.53	0.54	0.53	0.53	0.54	0.57	0.59	0.58	0.56	0.56	0.53	0.52
1.06	1.05	1.05	1.03	1.03	1.07	1.08	1.05	0.99	1.00	0.99	1.00	0.99	0.98
0.58	0.98	0.99	0.87	0.84	0.96	0.97	0.71	0.53	0.50	0.50	0.50	0.50	0.50
0.55	0.51	0.53	0.51	0.53	0.53	0.53	0.53	0.53	0.51	0.50	0.50	0.45	0.45
1.60	1.11	1.13	1.14	1.13	1.15	1.15	1.25	1.48	1.46	1.45	1.48	1.53	1.53
2.28	1.99	1.98	2.08	2.13	2.13	2.13	2.30	2.03	2.13	2.15	2.15	2.10	2.10
1.03	1.54	1.53	1.43	1.38	1.43	1.45	1.10	0.75	0.70	0.70	0.70	0.70	0.70
-0.02	0.23	0.27	0.13	0.13	0.33	0.33	0.20	0.23	0.23	0.23	0.23	0.23	0.23

1.6E-04	1.3E-04	1.3E-04	1.2E-04	1.3E-04	1.3E-04	1.2E-04	9.6E-05	7.2E-05	6.5E-05	6.6E-05	6.6E-05	6.6E-05	6.8E-05
1.5E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.1E-04	8.2E-05	7.5E-05	7.5E-05	7.5E-05	7.9E-05	8.0E-05
7.7E-05	6.9E-05	6.8E-05	6.7E-05	6.7E-05	6.3E-05	6.1E-05	5.8E-05	4.9E-05	4.4E-05	4.2E-05	4.2E-05	4.2E-05	4.2E-05
1.4E-04	7.4E-05	7.2E-05	7.9E-05	8.2E-05	7.0E-05	6.8E-05	8.5E-05	9.1E-05	8.7E-05	8.3E-05	8.3E-05	8.3E-05	8.3E-05
1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	9.2E-05	8.5E-05	8.3E-05	8.3E-05	9.3E-05	9.3E-05
5.1E-05	6.5E-05	6.3E-05	6.1E-05	6.1E-05	5.9E-05	5.7E-05	4.9E-05	3.3E-05	3.0E-05	2.9E-05	2.8E-05	2.7E-05	2.7E-05
3.6E-05	3.6E-05	3.6E-05	3.3E-05	3.2E-05	3.2E-05	3.1E-05	2.7E-05	2.4E-05	2.0E-05	1.9E-05	1.9E-05	2.0E-05	2.0E-05
8.0E-05	4.7E-05	4.6E-05	4.8E-05	5.0E-05	4.7E-05	4.5E-05	5.5E-05	6.4E-05	6.2E-05	6.0E-05	6.0E-05	6.0E-05	6.0E-05
-4.9E-03	3.1E-04	2.6E-04	5.2E-04	5.2E-04	2.0E-04	2.0E-04	3.0E-04	2.1E-04	1.9E-04	1.8E-04	1.8E-04	1.8E-04	1.8E-04

0.76	0.66	0.66	0.63	0.64	0.63	0.59	0.52	0.40	0.37	0.37	0.37	0.39	0.39	
0.60	0.53	0.52	0.51	0.52	0.49	0.47	0.45	0.37	0.34	0.32	0.32	0.33	0.33	
0.76	0.40	0.38	0.42	0.44	0.38	0.36	0.46	0.49	0.46	0.45	0.45	0.45	0.45	
0.78	0.61	0.63	0.58	0.62	0.61	0.56	0.46	0.35	0.31	0.32	0.32	0.32	0.32	4
0.74	0.70	0.67	0.67	0.66	0.64	0.63	0.58	0.46	0.42	0.42	0.42	0.46	0.46	5
0.49	0.62	0.60	0.58	0.59	0.56	0.55	0.47	0.31	0.28	0.28	0.27	0.26	0.26	1
0.53	0.54	0.53	0.49	0.48	0.47	0.46	0.39	0.35	0.30	0.29	0.29	0.29	0.29	2
0.65	0.38	0.38	0.40	0.41	0.39	0.37	0.45	0.53	0.51	0.49	0.49	0.49	0.49	6
-7.85	0.49	0.42	0.83	0.83	0.32	0.32	0.49	0.33	0.30	0.29	0.29	0.29	0.29	2

50A	35A	9A	21A	29A
14.49	14.14	14.25	14.67	14.46
18.70	18.7	18.5	19.9	19.1
15.04	14.69	14.81	15.2	15.04
0.55	0.55	0.56	0.53	0.58
0.55	0.55	0.54	0.58	0.56
0.00	0.00	0.02	-0.05	0.02
0.19	0.19	1.05	-2.59	1.15

Constant HeadTest

Date	15-Apr-07			Water Properties (T= 20C)				
Sand	French Drain	A (m2)	0.01039	γ (kN/m3)	9.7866	μ (Ns/m2)	9.8E-04	
Clay in suspension	0.5%	Battleford Till						

min min ml s
ml s min 7.366667

Time after beginning flow with suspension of fines (min)

	Elevation	Water	Water	Water	Water	Water	0	22	36	55	75	102	129	151	178	212	239	266	297	328	356	390	418	431	442
Pore volumes							0	1.5	2.4	3.6	4.8	6.4	7.9	9.0	10.3	11.9	13.0	14.0	15.1	16.0	16.8	17.7	18.3	18.6	18.8
Flow Rate Readings																									
Volume collected (mL)		166	152	118	116	97		92	89	86	82	78	73	70	65	59	55	50	45	40	37	33	29	27	27
Time taken to collect (s)		120	120	120	120	120		120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Temperature of water (C)		15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																									
Point 1 (cm)	1.5	47.8	48.3	49.4	49.4	48.4		48.1	48.1	47.7	47.6	47.3	47.2	47.0	46.7	46.3	46.0	45.6	45.3	44.8	44.5	43.9	43.3	43.2	43.2
Point 2 (cm)	3																								
Point 3 (cm)	4.5					47.5		47.2	47.1	46.7	46.6	46.2	46.1	45.9	45.5	45.1	44.7	44.2	43.8	43.3	42.9	42.3	41.7	41.6	41.6
Point 4 (cm)	8.5					42.8		42.3	42.2	41.8	41.1	41.1	40.7	40.3	39.8	39.1	38.6	37.9	37.3	36.6	36.1	35.4	34.8	34.6	34.5
Point 5 (cm)	12.5					39.2		38.9	38.7	38.3	38.1	37.6	37.2	36.8	36.3	35.6	35.1	34.6	34.1	33.5	33.0	32.5	32.0	31.8	31.7
Point 6 (cm)	16.5					34.9		34.7	34.6	34.4	34.2	33.9	33.6	33.4	33.0	32.6	32.3	32.0	31.6	31.3	31.0	30.6	30.4	30.3	30.2
Point 7 (cm)	20.5					32.3		32.2	32.1	32.0	31.9	31.7	31.5	31.3	31.1	30.9	30.7	30.5	30.3	30.1	29.9	29.7	29.5	29.4	29.4
Point 8 (cm)	22																								
Point 9 (cm)	23.5	30.1	30.1	30	30	29.7		29.7	29.7	29.6	29.6	29.5	29.4	29.3	29.2	29.1	29.0	28.9	28.8	28.8	28.7	28.6	28.5	28.5	28.5

1.266667	mL/s	1.27E-06		
1000	mL/L			
1000	L/m^3			

Calculations

Q (m3/s)		1.38E-06	1.27E-06	9.83E-07	9.67E-07	8.08E-07		7.667E-07	7.417E-07	7.167E-07	6.833E-07	6.5E-07	6.083E-07	5.83E-07	5.42E-07	4.92E-07	4.58E-07	4.17E-07	3.75E-07	3.33E-07	3.08E-07	2.75E-07	2.42E-07	2.25E-07	2.25E-07
i (Point 1-3)		15.93	16.10	16.47	16.47	0.30		0.30	0.33	0.33	0.33	0.37	0.37	0.37	0.40	0.40	0.43	0.47	0.50	0.50	0.53	0.53	0.53	0.53	0.53
i (Point 1-4)		6.83	6.90	7.06	7.06	0.80		0.83	0.84	0.84	0.93	0.89	0.93	0.96	0.99	1.03	1.06	1.10	1.14	1.17	1.20	1.21	1.21	1.23	1.24
i (Point 1-9)		0.80	0.83	0.88	0.88	0.85		0.84	0.84	0.82	0.82	0.81	0.81	0.80	0.80	0.78	0.77	0.76	0.75	0.73	0.72	0.70	0.67	0.67	0.67
i (Point 6-9)		-4.30	-4.30	-4.29	-4.29	0.74		0.94	0.94	0.92	0.92	0.91	0.91	0.91	0.90	0.89	0.88	0.86	0.84	0.83	0.81	0.79	0.76	0.76	0.76
i (Point 3-6)		0.00	0.00	0.00	0.00	1.05		1.04	1.04	1.03	1.03	1.03	1.04	1.04	1.04	1.04	1.03	1.02	1.02	1.00	0.99	0.98	0.94	0.94	0.95
i (Point 4-7)		0.00	0.00	0.00	0.00	0.88		0.84	0.84	0.82	0.77	0.78	0.77	0.75	0.73	0.68	0.66	0.62	0.58	0.54	0.52	0.48	0.44	0.43	0.43

K (m/s)

(Point 1-3)		8.4E-06	7.6E-06	5.7E-06	5.7E-06	2.6E-04		2.5E-04	2.1E-04	2.1E-04	2.0E-04	1.7E-04	1.6E-04	1.5E-04	1.3E-04	1.2E-04	1.0E-04	8.6E-05	7.2E-05	6.4E-05	5.6E-05	5.0E-05	4.4E-05	4.1E-05	4.1E-05
(Point 1-4)		1.95E-05	1.77E-05	1.34E-05	1.32E-05	9.73E-05		8.9E-05	8.5E-05	8.2E-05	7.1E-05	7.1E-05	6.3E-05	5.9E-05	5.3E-05	4.6E-05	4.2E-05	3.6E-05	3.2E-05	2.7E-05	2.5E-05	2.2E-05	1.9E-05	1.8E-05	1.7E-05
(Point 1-9)		1.66E-04	1.47E-04	1.07E-04	1.06E-04	9.16E-05		8.8E-05	8.5E-05	8.4E-05	8.0E-05	7.7E-05	7.2E-05	7.0E-05	6.6E-05	6.1E-05	5.7E-05	5.3E-05	4.8E-05	4.4E-05	4.1E-05	3.8E-05	3.5E-05	3.2E-05	3.2E-05
(Point 6-9)		-3.1E-05	-2.8E-05	-2.2E-05	-2.2E-05	1.0E-04		7.9E-05	7.6E-05	7.5E-05	7.2E-05	6.9E-05	6.4E-05	6.2E-05	5.8E-05	5.3E-05	5.0E-05	4.7E-05	4.3E-05	3.9E-05	3.7E-05	3.4E-05	3.1E-05	2.8E-05	2.8E-05
(Point 3-6)		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	7.4E-05		7.1E-05	6.9E-05	6.7E-05	6.4E-05	6.1E-05	5.6E-05	5.4E-05	5.0E-05	4.5E-05	4.3E-05	3.9E-05	3.6E-05	3.2E-05	3.0E-05	2.7E-05	2.5E-05	2.3E-05	2.3E-05
(Point 4-7)		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	8.9E-05		8.8E-05	8.5E-05	8.4E-05	8.6E-05	8.0E-05	7.6E-05	7.5E-05	7.2E-05	6.9E-05	6.7E-05	6.5E-05	6.2E-05	5.9E-05	5.7E-05	5.6E-05	5.3E-05	5.0E-05	5.1E-05

% of Ko (1-4)	Ko =				9.7E-05		1	0.92	0.87	0.84	0.73	0.73	0.65	0.60	0.54	0.47	0.43	0.37	0.32	0.28	0.25	0.22	0.20	0.18	0.18
% of Ko (1-9)	Ko =				9.2E-05		1.00	0.96	0.93	0.92	0.88	0.84	0.79	0.76	0.72	0.66	0.62	0.58	0.53	0.48	0.45	0.42	0.38	0.35	0.35
% of Ko (6-9)	Ko =				1.0E-04		1.00	0.75	0.73	0.72	0.68	0.66	0.61	0.59	0.55	0.51	0.48	0.45	0.41	0.37	0.35	0.32	0.29	0.27	0.27

French Drain Sand with Regina Clay

Constant HeadTest min ml s

Test W (1st column) ml s min 1753.2 43 grams

Date 25-Jul-07 Water Properties (T= 20C)

Sand French Drain sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 8.7 L

Clay in suspension 0.5% (Regina clay) Complete stoppage of flow when checked the next morning

Time after beginning flow with suspension of fines (min)	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	3	7	12	19	35	51	68	79	319	458
Pore volumes								0	0.2	0.6	0.9	1.5	2.6	3.6	4.6	5.1	11.7	12.6
Volume collected (mL)		75	60	58	55.5	55.5	55		55	54	51	50.5	47	41	36	32	12	5
Time taken to collect (s)		60	60	60	60	60	60		60	60	60	60	60	60	60	60	120	120
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15
Manometer Readings																		
Point 1 (cm)	1.5	48.05	48.6	49.05	49.8	50	50.05		50.3	50.3	50.2	50.1	50.2	49.8	49.4	48.4	43.7	37.0
Point 2 (cm)	3																	
Point 3 (cm)	4.5	46.2	46.7				48.4		48.5	48.5	48.5	48.5	48.4	48.0	47.5	46.2	35.0	31.2
Point 4 (cm)	8.5	41.1	42.4				44.1		44.1	44.2	43.9	43.8	43.6	42.3	41.0	39.8	30.3	29.0
Point 5 (cm)	12.5	37	37.2				38.4		38.4	38.2	37.8	37.6	37.1	35.9	34.9	34.2	29.2	28.5
Point 6 (cm)	16.5	34.3	34.4				35.2		35.2	35.2	35.0	34.9	34.6	33.9	33.2	32.7	28.9	28.4
Point 7 (cm)	20.5	31	31				31.2		31.2	31.2	30.9	30.9	30.9	30.5	30.3	30.0	28.4	28.2
Point 8 (cm)	22																	
Point 9 (cm)	23.5	29.35	29.3	29.35	29.35	29.4	29.4		29.4	29.4	29.2	29.2	29.2	29.1	28.9	28.8	28.0	27.9
			1		0.000001													
			1000	mL/L			Turb.	0	1.2	2.7	2.0	3.4	6.5	7.6	5.2	4.7	26	21
Calculations			1000	L/m^3														
Q (m3/s)		1.25E-06	0.000001	9.67E-07	9.25E-07	9.25E-07	9.17E-07		9.167E-07	0.0000009	8.5E-07	8.417E-07	7.833E-07	6.833E-07	0.0000006	5.333E-07	0.0000001	4.167E-08
i (Point 1-3)		0.62	0.63	16.35	16.60	16.67	0.55		0.58	0.58	0.57	0.53	0.58	0.58	0.62	0.73	2.88	1.93
i (Point 1-4)		0.99	0.89	7.01	7.11	7.14	0.85		0.88	0.87	0.90	0.89	0.94	1.06	1.19	1.23	1.91	1.14
i (Point 1-9)		0.85	0.88	0.90	0.93	0.94	0.94		0.95	0.95	0.95	0.95	0.95	0.94	0.93	0.89	0.71	0.42
i (Point 6-9)		0.71	0.73	-4.19	-4.19	-4.20	0.83		0.83	0.83	0.82	0.81	0.78	0.69	0.62	0.56	0.14	0.08
i (Point 3-4)		1.28	1.08	0.00	0.00	0.00	1.08		1.10	1.09	1.15	1.16	1.20	1.43	1.63	1.60	1.18	0.55
i (Point 4-5)		1.03	1.30	0.00	0.00	0.00	1.43		1.43	1.49	1.51	1.55	1.63	1.60	1.53	1.40	0.28	0.13
i (Point 5-6)		0.68	0.70	0.00	0.00	0.00	0.80		0.80	0.76	0.71	0.69	0.63	0.50	0.42	0.38	0.08	0.03
i (Point 6-7)		0.82	0.85	0.00	0.00	0.00	1.00		1.00	0.99	1.01	0.99	0.93	0.85	0.74	0.68	0.14	0.05
i (Point 7-9)		0.55	0.57	-9.78	-9.78	-9.80	0.60		0.60	0.62	0.57	0.57	0.58	0.48	0.47	0.42	0.13	0.12
K (m/s)																		
(Point 1-3)		2.0E-04	1.5E-04	5.7E-06	5.4E-06	5.3E-06	1.6E-04		1.5E-04	1.5E-04	1.4E-04	1.5E-04	1.3E-04	1.1E-04	9.4E-05	7.0E-05	3.3E-06	2.1E-06
(Point 1-4)		1.2E-04	1.1E-04	1.3E-05	1.3E-05	1.2E-05	1.0E-04		1.0E-04	9.9E-05	9.1E-05	9.1E-05	8.1E-05	6.2E-05	4.8E-05	4.2E-05	5.0E-06	3.5E-06
(Point 1-9)		1.4E-04	1.1E-04	1.0E-04	9.6E-05	9.5E-05	9.4E-05		9.3E-05	9.1E-05	8.6E-05	8.6E-05	7.9E-05	7.0E-05	6.2E-05	5.7E-05	1.3E-05	9.6E-06
(Point 6-9)		1.7E-04	1.3E-04	-2.2E-05	-2.1E-05	-2.1E-05	1.1E-04		1.1E-04	1.0E-04	1.0E-04	1.0E-04	9.7E-05	9.5E-05	9.3E-05	9.1E-05	7.1E-05	5.1E-05
(Point 3-4)		9.4E-05	9.0E-05	#DIV/0!	#DIV/0!	#DIV/0!	8.2E-05		8.0E-05	8.0E-05	7.1E-05	7.0E-05	6.3E-05	4.6E-05	3.6E-05	3.2E-05	8.2E-06	7.3E-06
(Point 4-5)		1.2E-04	7.4E-05	#DIV/0!	#DIV/0!	#DIV/0!	6.2E-05		6.2E-05	5.8E-05	5.4E-05	5.2E-05	4.6E-05	4.1E-05	3.8E-05	3.7E-05	3.5E-05	3.2E-05
(Point 5-6)		1.8E-04	1.4E-04	#DIV/0!	#DIV/0!	#DIV/0!	1.1E-04		1.1E-04	1.1E-04	1.1E-04	1.2E-04	1.2E-04	1.3E-04	1.4E-04	1.4E-04	1.3E-04	1.6E-04
(Point 6-7)		1.5E-04	1.1E-04	#DIV/0!	#DIV/0!	#DIV/0!	8.8E-05		8.8E-05	8.8E-05	8.1E-05	8.2E-05	8.2E-05	7.7E-05	7.8E-05	7.6E-05	7.0E-05	8.0E-05
(Point 7-9)		2.2E-04	1.7E-04	-9.5E-06	-9.1E-06	-9.1E-06	1.5E-04		1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.4E-04	1.2E-04	1.2E-04	7.2E-05	3.4E-05

% of Ko (1-4)	Ko =					1.0E-04		1.00	0.97	0.96	0.88	0.87	0.78	0.60	0.47	0.40	0.05	0.03
% of Ko (1-9)	Ko =					9.4E-05		1.00	0.99	0.97	0.91	0.91	0.84	0.74	0.66	0.61	0.14	0.10
% of Ko (6-9)	Ko =					1.1E-04		1.00	1.00	0.98	0.94	0.94	0.91	0.89	0.87	0.85	0.67	0.48
% of Ko (1-3)	Ko =					1.6E-04		1.00	0.94	0.93	0.90	0.95	0.81	0.70	0.58	0.44	0.02	0.01
% of Ko (3-4)	Ko =					8.2E-05		1.00	0.98	0.97	0.87	0.85	0.77	0.56	0.43	0.39	0.10	0.09
% of Ko (4-5)	Ko =					6.2E-05		1.00	1.00	0.94	0.87	0.84	0.75	0.66	0.61	0.59	0.57	0.52
% of Ko (5-6)	Ko =					1.1E-04		1.00	1.00	1.03	1.04	1.07	1.09	1.19	1.23	1.24	1.16	1.45
% of Ko (6-7)	Ko =					8.8E-05		1.00	1.00	0.99	0.92	0.93	0.92	0.88	0.89	0.86	0.79	0.91
% of Ko (7-9)	Ko =					1.5E-04		1.00	1.00	0.96	0.98	0.97	0.88	0.93	0.84	0.84	0.49	0.23

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
W-1	222.11	2151.70	2108.94	42.76	2.2%	
W-2	78.29	715.44	696.67	18.77	2.9%	4
W-3	85.91	651.46	631.79	19.67	3.5%	2
W-4	83.50	854.40	821.06	33.34	4.3%	1
	469.81	4373.00	4258.46	114.54	2.9%	
		Post-test total mass of fines		115 g		0.027
		Mass of fines injected		43 g		

Tare	13.20	14.6	13.45
Volume	9.90	9.4	9.85
Mass Before	23.18	24.13	23.36
Mass After	13.49	14.89	13.74
g solids	0.29	0.29	0.29
g salt	0.29	0.27	0.29
g clay	0.00	0.02	0.00
clay (g/L)	0.07	1.63	0.22

Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

Constant HeadTest

									min		ml	s											
	Test X	(2nd column)								ml	s	min				1753.2			37 grams			38000	1.06
Date	25-Jul-07									Water Properties (T= 20C)												40280	
Sand	French Drain sand		A (m2)	0.01039						γ (kN/m3)	9.7866	μ (Ns/m2)	9.8E-04					31.0	37.4	40.7	42.0	52.8	54.0
Clay in suspension	0.1% (Regina clay)																Estimated - bottle empty when returned - restarted test next morning.						
Time after beginning flow with suspension of fines (min)	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	3	8	14	29	46	58	71	297	420	570	738	833	872	1265	1318
Pore volumes								0	0.4	1.0	1.7	3.4	5.2	6.4	7.7	27.4	35.9	45.0	54.3	59.1	61.0	76.7	78.4
Volume collected (mL)		109	81	82	84.5	85	85.5		85	83	80	76.5	71.5	69	67	53	42.5	40.5	36	34	32	23	21.5
Time taken to collect (s)		60	60	60	60	60	60		60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																							
Point 1 (cm)	4.2	46	48.3	48.3	48.1	48.1	48		48.2	48.3	48.4	48.9	49.3	49.6	49.8	51.1	51.0	51.4	52.0	52.1	52.3	53.2	53.3
Point 2 (cm)	5.8																						
Point 3 (cm)	7.2	43.8	46				46.3		46.5	46.6	46.8	47.3	47.8	48.1	48.3	49.5	48.1	47.7	47.5	46.6	42.0	43.9	44.3
Point 4 (cm)	11.2	39.7	41				43.1		43.2	43.4	43.5	43.9	44.9	44.6	44.8	46.9	44.0	43.3	43.5	43.2	43.2	42.7	42.5
Point 5 (cm)	15.2	32.8	32.7				35.9		35.9	35.8	35.6	35.1	34.7	34.5	34.3	34.1	32.9	33.0	32.5	32.7	32.6	31.5	31.3
Point 6 (cm)	19.2	31.05	31.1				32.6		32.6	32.6	32.5	32.4	32.2	32.2	32.1	32.2	30.9	31.0	31.0	31.1	31.0	30.3	30.2
Point 7 (cm)	23.2	28.85	28.6				28.9		28.9	28.9	28.9	28.8	28.7	28.7	28.7	28.6	28.6	28.6	28.4	28.5	28.5	28.4	28.3
Point 8 (cm)	24.7																						
Point 9 (cm)	26.2	28.1	28	28	28.15	28.15	28.2		28.2	28.2	28.2	28.2	28.1	28.1	28.1	27.9	27.7	27.7	27.6	27.6	27.6	27.5	27.5
			1.35		1.35E-06																		
			1000 mL/L				Turb.	0	8	18	23	24	26	23	26	108	78	160	133	176	116	130	140
Calculations			1000 L/m^3																				
Q (m3/s)		1.82E-06	1.35E-06	1.37E-06	1.41E-06	1.42E-06	1.43E-06		1.417E-06	1.383E-06	1.333E-06	1.275E-06	1.192E-06	1.15E-06	1.117E-06	8.833E-07	7.083E-07	6.75E-07	0.0000006	5.67E-07	5.33E-07	3.83E-07	3.58E-07
i (Point 1-3)		0.73	0.77	16.10	16.03	16.03	0.57		0.55	0.57	0.53	0.53	0.50	0.48	0.48	0.53	0.97	1.22	1.48	1.82	3.42	3.08	2.98
i (Point 1-4)		0.90	1.04	6.90	6.87	6.87	0.70		0.71	0.70	0.70	0.71	0.63	0.71	0.71	0.60	1.00	1.15	1.21	1.26	1.29	1.49	1.54
i (Point 1-9)		0.81	0.92	0.92	0.91	0.91	0.90		0.91	0.91	0.92	0.94	0.96	0.98	0.99	1.06	1.06	1.08	1.11	1.11	1.12	1.17	1.17
i (Point 6-9)		0.42	0.44	-4.00	-4.02	-4.02	0.63		0.63	0.63	0.61	0.61	0.59	0.59	0.58	0.62	0.46	0.48	0.49	0.50	0.49	0.40	0.39
i (Point 3-4)		1.03	1.25	0.00	0.00	0.00	0.80		0.83	0.80	0.83	0.85	0.73	0.88	0.88	0.65	1.03	1.10	1.00	0.85	-0.30	0.30	0.45
i (Point 4-5)		1.73	2.08	0.00	0.00	0.00	1.80		1.83	1.90	1.98	2.20	2.55	2.53	2.63	3.20	2.78	2.58	2.75	2.63	2.65	2.80	2.80
i (Point 5-6)		0.44	0.40	0.00	0.00	0.00	0.82		0.82	0.80	0.78	0.68	0.63	0.57	0.55	0.48	0.50	0.50	0.38	0.40	0.40	0.30	0.28
i (Point 6-7)		0.55	0.63	0.00	0.00	0.00	0.93		0.93	0.93	0.90	0.90	0.88	0.88	0.85	0.90	0.57	0.61	0.65	0.65	0.63	0.48	0.48
i (Point 7-9)		0.25	0.20	-9.33	-9.38	-9.38	0.23		0.23	0.23	0.23	0.22	0.20	0.22	0.22	0.25	0.30	0.30	0.28	0.30	0.32	0.30	0.27
K (m/s)																							
(Point 1-3)		2.4E-04	1.7E-04	8.2E-06	8.5E-06	8.5E-06	2.4E-04		2.5E-04	2.4E-04	2.4E-04	2.3E-04	2.3E-04	2.3E-04	2.2E-04	1.6E-04	7.1E-05	5.3E-05	3.9E-05	3.0E-05	1.5E-05	1.2E-05	1.2E-05
(Point 1-4)		1.9E-04	1.2E-04	1.9E-05	2.0E-05	2.0E-05	2.0E-04		1.9E-04	1.9E-04	1.8E-04	1.7E-04	1.8E-04	1.6E-04	1.5E-04	1.4E-04	6.8E-05	5.7E-05	4.8E-05	4.3E-05	4.0E-05	2.5E-05	2.2E-05
(Point 1-9)		2.1E-04	1.4E-04	1.4E-04	1.5E-04	1.5E-04	1.5E-04		1.5E-04	1.5E-04	1.4E-04	1.3E-04	1.2E-04	1.1E-04	1.1E-04	8.0E-05	6.4E-05	6.0E-05	5.2E-05	4.9E-05	4.6E-05	3.2E-05	2.9E-05
(Point 6-9)		4.2E-04	2.9E-04	-3.3E-05	-3.4E-05	-3.4E-05	2.2E-04		2.2E-04	2.1E-04	2.1E-04	2.0E-04	2.0E-04	1.9E-04	1.9E-04	1.4E-04	1.5E-04	1.4E-04	1.2E-04	1.1E-04	1.0E-04	9.2E-05	8.9E-05
(Point 3-4)		1.7E-04	1.0E-04	#DIV/0!	#DIV/0!	#DIV/0!	1.7E-04		1.7E-04	1.7E-04	1.6E-04	1.4E-04	1.6E-04	1.3E-04	1.2E-04	1.3E-04	6.7E-05	5.9E-05	5.8E-05	6.4E-05	-1.7E-04	1.2E-04	7.7E-05
(Point 4-5)		1.0E-04	6.3E-05	#DIV/0!	#DIV/0!	#DIV/0!	7.6E-05		7.5E-05	7.0E-05	6.5E-05	5.6E-05	4.5E-05	4.4E-05	4.1E-05	2.7E-05	2.5E-05	2.5E-05	2.1E-05	2.1E-05	1.9E-05	1.3E-05	1.2E-05
(Point 5-6)		4.0E-04	3.2E-04	#DIV/0!	#DIV/0!	#DIV/0!	1.7E-04		1.7E-04	1.7E-04	1.7E-04	1.8E-04	1.8E-04	1.9E-04	2.0E-04	1.8E-04	1.4E-04	1.3E-04	1.5E-04	1.4E-04	1.3E-04	1.2E-04	1.3E-04
(Point 6-7)		3.2E-04	2.1E-04	#DIV/0!	#DIV/0!	#DIV/0!	1.5E-04		1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	9.4E-05	1.2E-04	1.1E-04	8.9E-05	8.4E-05	8.2E-05	7.8E-05	7.3E-05
(Point 7-9)		7.0E-04	6.5E-04	-1.4E-05	-1.4E-05	-1.5E-05	5.9E-04		5.8E-04	5.7E-04	5.5E-04	5.7E-04	5.7E-04	5.1E-04	5.0E-04	3.4E-04	2.3E-04	2.2E-04	2.0E-04	1.8E-04	1.6E-04	1.2E-04	1.3E-04
% of Ko (1-4)	Ko =					2.0E-04		1.00	0.98	0.97	0.94	0.88	0.93	0.80	0.78	0.72	0.35	0.29	0.24	0.22	0.20	0.13	0.11
% of Ko (1-9)	Ko =					1.5E-04		1.00	0.99	0.96	0.92	0.85	0.78	0.74	0.72	0.53	0.42	0.40	0.34	0.32	0.30	0.21	0.19
% of Ko (6-9)	Ko =					2.2E-04		1.00	0.99	0.97	0.96	0.93	0.90	0.86	0.85	0.63	0.68	0.62	0.54	0.50	0.48	0.42	0.41
% of Ko (1-3)	Ko =					2.4E-04		1.00	1.02	0.97	0.99	0.95	0.95	0.95	0.92	0.66	0.29	0.22	0.16	0.12	0.06	0.05	0.05
% of Ko (3-4)	Ko =					1.7E-04		1.00	0.96	0.97	0.91	0.84	0.92	0.74	0.72	0.76	0.39	0.34	0.34	0.37	-1.00	0.72	0.45
% of Ko (4-5)	Ko =					7.6E-05		1.00	0.98	0.92	0.85	0.73	0.59	0.58	0.54	0.35	0.32	0.33	0.28	0.27	0.25	0.17	0.16
% of Ko (5-6)	Ko =					1.7E-04		1.00	0.99	1.00	1.00	1.09	1.10	1.16	1.18	1.08	0.82	0.78	0.93	0.82	0.77	0.74	0.75
% of Ko (6-7)	Ko =					1.5E-04		1.00	0.99	0.97	0.96	0.92	0.88	0.85	0.85	0.64	0.80	0.72	0.60	0.57	0.55	0.52	0.49
% of Ko (7-9)	Ko =					5.9E-04		1.00	0.99	0.97	0.94	0.96	0.98	0.87	0.84	0.58	0.39	0.37	0.35	0.31	0.28	0.21	0.22

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines									
X-1	89.28	674.03	654.31	19.72	3.4%	4	Tare	14.28	14.07	13.50	14.34	14.34	14.08
X-2	88.40	660.60	643.65	16.95	3.0%	5	Volume	9.95	9.40	9.75	9.95	9.70	9.60
X-3	99.98	785.70	763.35	22.35	3.3%	6	Mass Before	24.29	23.57	23.29			
X-4	102.06	791.97	765.15	26.82	3.9%	1	Mass After	14.57	14.35	13.79	14.66	14.63	14.40
X-5	91.81	711.72	686.86	24.86	4.0%	3	g solids	0.29	0.28	0.29	0.32	0.29	0.32
X-6	90.72	724.11	694.40	29.71	4.7%	2	g salt	0.29	0.27	0.28	0.29	0.28	0.28
	562.25	4348.13	4207.72	140.41	3.7%		g clay	0.00	0.01	0.01	0.03	0.01	0.04
							clay (g/L)	-0.07	0.57	0.52	2.94	0.68	4.11
			Post-test total mass of fines	140 g									
			Mass of fines injected	67 g									

0.0334 Note: The french drain sand initially contained approximately 3% fines (roughly 125 g).

				67 grams
62.2	64.8	66.1	67.3	
			38.15	

1777	2000	2144	2289
90.3	94.1	95.9	97.7
14	19	17	16
60	120	120	120
15	15	15	15
53.4	47.1	42.8	40.2
41.2	38.5	36.2	34.6
41.4	39.9	38.8	38.3
30.4	29.6	29.3	29.4
29.4	28.9	28.7	28.7
28.2	27.9	27.8	27.9
27.4	27.3	27.3	27.3

149	105	250	123

2.33E-07	1.58E-07	1.42E-07	1.333E-07
4.07	2.85	2.18	1.87
1.71	1.02	0.56	0.27
1.18	0.90	0.70	0.59
0.29	0.23	0.21	0.21
-0.05	-0.35	-0.65	-0.92
2.75	2.58	2.38	2.23
0.25	0.18	0.15	0.18
0.30	0.25	0.23	0.20
0.27	0.20	0.18	0.22

5.5E-06	5.3E-06	6.2E-06	6.9E-06
1.3E-05	1.5E-05	2.4E-05	4.7E-05
1.9E-05	1.7E-05	1.9E-05	2.2E-05
7.9E-05	6.7E-05	6.6E-05	6.2E-05
-4.5E-04	-4.4E-05	-2.1E-05	-1.4E-05
8.2E-06	5.9E-06	5.7E-06	5.8E-06
9.0E-05	8.7E-05	9.1E-05	7.3E-05
7.5E-05	6.1E-05	6.1E-05	6.4E-05
8.4E-05	7.6E-05	7.4E-05	5.9E-05

0.07	0.08	0.12	0.24
0.12	0.11	0.13	0.14
0.36	0.31	0.30	0.28
0.02	0.02	0.03	0.03
-2.62	-0.25	-0.12	-0.08
0.11	0.08	0.08	0.08
0.54	0.52	0.55	0.44
0.50	0.41	0.41	0.43
0.14	0.13	0.13	0.10

	14.28		14.25
	9.70		9.90
	14.59		14.58
	0.31		0.33
	0.28		0.29
	0.03		0.04
	2.74		4.11

Uniform Sand with Kaolinite

Constant HeadTest min ml s

Test Z 2nd setup ml s min — 978 grams

Date 27-Jul-07 — Water Properties (T= 20C)

Sand Unimin sand A (m2) 0.01039 — γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 — 196 litres

Clay in suspension 0.5% (kaolinite)

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2.5	6	15	39	115	347	603	839	1044
Pore volumes									0	0.6	1.4	3.5	9.0	26.0	74.6	121.8	158.1	184.7
		Flow Rate Readings																
Volume collected (mL)			122.5	122	121	122	122	122		122	122	122	121	117	105	90	73	64.5
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15
	0bmeter Readings						55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	29.1	29	28.95	28.9	28.9			28.9	29.0	29.1	29.3	30.0	33.5	36.2	39.0	40.3
Point 4 (cm)	8.5	11.2					28.6			28.6	28.7	28.7	28.8	29.3	31.1	33.4	34.8	36.2
Point 6 (cm)	16.5	19.2					28.3			28.3	28.3	28.3	28.4	28.5	29.4	30.4	31.1	31.8
Point 9 (cm)	23.5	26.2	28	27.85	27.8	27.75	27.75			27.8	27.8	27.8	27.8	27.8	27.9	28.1	28.0	28.2
	25			4.066667	mL/s	4.07E-06	28	28	28	28	28	28	28	28	28	28	28	28
				1000	mL/L			Turb.	0	1.4	833	1100						
Calculations				1000	L/m^3													
Q (m3/s)			4.08E-06	4.07E-06	4.03E-06	4.07E-06	4.07E-06	4.07E-06		4.067E-06	4.067E-06	4.067E-06	4.033E-06	0.0000039	0.0000035	0.000003	2.433E-06	2.15E-06
i (Point 1-4)			4.16	4.14	4.14	4.13	0.04	0.00		0.04	0.04	0.05	0.06	0.11	0.34	0.39	0.60	0.59
i (Point 1-9)			0.05	0.05	0.05	0.05	0.05	0.00		0.05	0.05	0.06	0.07	0.10	0.26	0.37	0.50	0.55
i (Point 6-9)			-4.00	-3.98	-3.97	-3.96	0.08	0.00		0.08	0.08	0.08	0.09	0.10	0.22	0.34	0.44	0.52
i (Point 4-6)			0.00	0.00	0.00	0.00	0.04	0.00		0.04	0.04	0.05	0.06	0.10	0.21	0.38	0.46	0.55
K (m/s)																		
(Point 1-4)			9.5E-05	9.5E-05	9.4E-05	9.5E-05	9.1E-03	#DIV/0!		9.1E-03	9.1E-03	7.8E-03	6.0E-03	3.5E-03	9.8E-04	7.4E-04	3.9E-04	3.5E-04
(Point 1-9)			7.9E-03	7.5E-03	7.4E-03	7.5E-03	7.5E-03	#DIV/0!	7.5E-03	7.5E-03	7.2E-03	6.6E-03	5.7E-03	3.7E-03	1.3E-03	7.8E-04	4.7E-04	3.7E-04
(Point 6-9)			-9.8E-05	-9.8E-05	-9.8E-05	-9.9E-05	5.0E-03	#DIV/0!		5.0E-03	5.0E-03	5.0E-03	4.5E-03	3.8E-03	1.5E-03	8.6E-04	5.3E-04	4.0E-04
(Point 4-6)			#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1.0E-02	#DIV/0!		1.0E-02	8.9E-03	7.8E-03	6.9E-03	3.8E-03	1.6E-03	7.7E-04	5.1E-04	3.8E-04
									7.5E-01	7.5E-01	7.2E-01	6.6E-01	5.7E-01	3.7E-01	1.3E-01	7.8E-02	4.7E-02	3.7E-02
% of Ko (1-4)		Ko =					9.1E-03		1.00	1.00	1.00	0.86	0.66	0.38	0.11	0.08	0.04	0.04
% of Ko (1-9)		Ko =					7.5E-03		1.00	1.00	0.96	0.88	0.76	0.49	0.18	0.10	0.06	0.05
% of Ko (6-9)		Ko =					5.0E-03		1.00	1.00	1.00	1.00	0.91	0.75	0.31	0.17	0.11	0.08
% of Ko (4-6)		Ko =					1.0E-02		1.00	1.00	0.86	0.75	0.66	0.36	0.15	0.07	0.05	0.04

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines			Tare	14.27		14.16	14.09	13.47	13.51	14.15	13.49
Z-1	84.44	662.09	642.90	19.19	3.3%	3		Volume	10.00		9.90	10.00	9.85	9.85	9.80	9.80
Z-2	87.03	663.04	643.37	19.67	3.4%			Mass After	14.27		14.20	14.12	13.52	13.57	14.20	13.54
Z-3	91.25	739.68	717.06	22.62	3.5%	1		g solids	0.00		0.04	0.03	0.05	0.06	0.05	0.05
Z-4	88.66	582.18	563.17	19.01	3.9%			g clay	0.00		0.04	0.03	0.05	0.06	0.05	0.05
Z-5	90.87	654.26	634.19	20.07	3.6%			clay (g/L)	0.00		4.04	3.00	5.08	6.09	5.10	5.10
Z-6	91.52	706.67	681.98	24.69	4.0%	1										
	5.3E+02	4.0E+03	3.9E+03	1.3E+02	3.6%											
		Post-test total mass of fines		125 g		0.032										
		Mass of fines injected		978 g												
				12.8%												

Constant HeadTest

	Test M			min		ml	s
					ml	s	min
Date	03-Jul-07				Water Properties (T= 20C)		
Sand	Unimin sand	A (m2)	0.01039		γ (kN/m3)	9.7866 μ (Ns/m2)	9.8E-04
Clay in suspension	0.5% (kaolinite)						

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2	4	7	12	20	33	48	63	77	97	346	391	617	662
Pore volumes									0	0.5	0.9	1.6	2.7	4.5	7.4	10.7	14.0	17.1	21.4	71.9	80.3	119.4	126.8
		Flow Rate Readings																					
Volume collected (mL)			119	121	126	122	120	122		122	121	121	118	115	120	117	115	116	113	102	96	131	128
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	45	45
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings						55		55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	1.5	30	30	29.9	29.85	29.85	29.8		29.9	29.9	29.9	29.9	30.0	30.2	30.2	30.4	30.6	30.7	34.3	34.5	36.6	37.6
Point 4 (cm)	8.5	8.5	29.9	29.75	29.7	29.6	29.6	29.6		29.6	29.6	29.6	29.6	29.6	29.8	29.9	29.9	30.0	30.1	32.2	32.5	35.3	35.9
Point 6 (cm)	16.5	16.5	29.55	29.4	29.35	29.25	29.2	29.2		29.2	29.2	29.2	29.2	29.2	29.3	29.3	29.4	29.4	29.4	30.5	30.6	31.5	31.7
Point 9 (cm)	23.5	23.5	29.1	28.85	28.85	28.75	28.65	28.65		28.7	28.7	28.7	28.7	28.6	28.7	28.7	28.7	28.7	28.7	29.0	29.0	29.1	29.2
	25			4.033333	mL/s	4.03E-06		28		28	28	28	28	28	28	28	28	28	28	28	28	28	28
				1000	mL/L			Turb.	0	0.8	153	281	554	1100									
Calculations				1000	L/m^3					17.217391													
Q (m3/s)			3.97E-06	4.03E-06	4.2E-06	4.07E-06	0.000004	0.000004	0.000070	4.067E-06	4.033E-06	4.033E-06	3.933E-06	3.833E-06	0.000004	0.0000039	3.833E-06	3.867E-06	3.767E-06	0.0000034	3.2E-06	2.91E-06	2.84E-06
i (Point 1-4)			0.01	0.04	0.03	0.04	0.04	0.03		0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.07	0.08	0.09	0.30	0.29	0.18	0.24
i (Point 1-9)			0.04	0.05	0.05	0.05	0.05	0.05	0.90	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.09	0.09	0.24	0.25	0.34	0.38
i (Point 6-9)			0.06	0.08	0.07	0.07	0.08	0.08		0.07	0.07	0.07	0.07	0.08	0.09	0.09	0.10	0.11	0.11	0.21	0.24	0.34	0.36
i (Point 4-6)			0.04	0.04	0.04	0.04	0.05	0.05		0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.08	0.08	0.22	0.24	0.48	0.53
							V =	0.0003915	0.0067409	17.22													
							V*e =	0.0005873	0.0101114	17.22													
K (m/s)																							
(Point 1-4)			2.7E-02	1.1E-02	1.4E-02	1.1E-02	1.1E-02	1.4E-02		1.1E-02	1.1E-02	1.1E-02	8.8E-03	7.4E-03	7.7E-03	8.8E-03	5.2E-03	4.7E-03	3.9E-03	1.1E-03	1.1E-03	1.6E-03	1.2E-03
(Point 1-9)			9.3E-03	7.4E-03	8.5E-03	7.8E-03	7.1E-03	7.5E-03		7.2E-03	7.1E-03	7.1E-03	6.7E-03	6.0E-03	5.6E-03	5.5E-03	4.6E-03	4.3E-03	3.9E-03	1.3E-03	1.2E-03	8.3E-04	7.2E-04
(Point 6-9)			5.9E-03	4.9E-03	5.7E-03	5.5E-03	4.9E-03	5.0E-03		5.5E-03	5.4E-03	5.4E-03	5.3E-03	4.7E-03	4.1E-03	4.0E-03	3.7E-03	3.5E-03	3.4E-03	1.5E-03	1.3E-03	8.2E-04	7.5E-04
(Point 4-6)			8.7E-03	8.9E-03	9.2E-03	8.9E-03	7.7E-03	7.8E-03		7.0E-03	6.9E-03	6.9E-03	6.7E-03	6.6E-03	6.2E-03	5.5E-03	5.4E-03	5.0E-03	4.5E-03	1.5E-03	1.3E-03	5.9E-04	5.2E-04
									v = ki	3.9E-04	3.9E-04	3.9E-04	3.8E-04	3.7E-04	3.9E-04	3.8E-04	3.7E-04	3.7E-04	3.6E-04	3.3E-04	3.1E-04	2.8E-04	2.7E-04
% of Ko (1-4)		Ko =					1.4E-02		1.00	0.80	0.79	0.79	0.64	0.54	0.56	0.64	0.38	0.35	0.28	0.08	0.08	0.11	0.08
% of Ko (1-9)		Ko =					7.5E-03		1.00	0.96	0.95	0.95	0.89	0.80	0.75	0.74	0.62	0.58	0.52	0.18	0.16	0.11	0.10
% of Ko (6-9)		Ko =					5.0E-03		1.00	1.10	1.09	1.09	1.06	0.94	0.83	0.81	0.74	0.70	0.68	0.31	0.26	0.16	0.15
% of Ko (4-6)		Ko =					7.8E-03		1.00	0.89	0.88	0.88	0.86	0.84	0.79	0.70	0.69	0.63	0.57	0.19	0.17	0.08	0.07

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
M-1		1230.20	1217.60	12.60	1.0%	3
M-2		1055.40	1042.90	12.50	1.2%	2
M-3		1168.10	1142.20	25.90	2.2%	1
		3453.70	3402.70	51.00	1.5%	
	Post-test total mass of fines			51 g		1.5E-02
	Mass of fines injected			844 g		
				6.0%		

844 g

168.9 L

715	772	861
135.0	143.5	159.4
120	115	113
45	45	30
15	15	15
55	55	55
37.8	37.8	33.2
35.9	35.9	32.0
31.8	31.8	30.6
29.2	29.2	29.1
28	28	28

2.67E-06	2.56E-06	3.77E-06
0.26	0.26	0.17
0.39	0.39	0.19
0.38	0.38	0.22
0.51	0.51	0.17

9.7E-04	9.3E-04	2.1E-03
6.6E-04	6.3E-04	1.9E-03
6.8E-04	6.5E-04	1.6E-03
5.0E-04	4.8E-04	2.1E-03
2.6E-04	2.5E-04	3.6E-04
0.07	0.07	0.15
0.09	0.08	0.26
0.14	0.13	0.33
0.06	0.06	0.27

Inflow tube became unplugged.
Restarted flow but the k jumped.

Constant HeadTest min ml s

Test N ml s min 38000 1.06

Date 05-Jul-07 Water Properties (T= 20C) 40280

Sand Unimin sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 85.6

Clay in suspension 0.1% (kaolinite)

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2	5	8	13	19	27	36	47	57	75	86	110	130	200	234	360
Pore volumes								0	0.5	1.1	1.8	2.9	4.3	6.1	8.1	10.5	12.7	16.7	19.2	24.8	29.4	45.4	53.0	80.8
Flow Rate Readings																								
Volume collected (mL)		125	123	126	119	120	120		120	120	120	120	119	118	117	116	116	120	123	122	122	120	118	116
Time taken to collect (s)		30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0						55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	29.65	29.8	29.8	29.7	29.7	29.7		29.7	29.7	29.7	29.7	29.8	29.8	29.8	29.8	29.9	30.2	30.2	30.3	30.4	30.6	30.8	31.3
Point 4 (cm)	8.5	29.45	29.65	29.65	29.5	29.6	29.55		29.6	29.5	29.5	29.5	29.6	29.6	29.6	29.6	29.7	29.8	29.8	29.9	29.9	30.1	30.2	30.6
Point 6 (cm)	16.5	29.1	29.25	29.25	29.1	29.1	29.1		29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.2	29.3	29.3	29.3	29.3	29.4	29.4	29.6
Point 9 (cm)	23.5	28.65	28.75	28.75	28.6	28.6	28.65		28.7	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7
	25		4.1		4.1E-06		28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
			1000 mL/L				Turb.	0	1.8	44	55	64	75	98	128	166	186	310	299	387	383	578	654	767
Calculations			1000 L/m^3																					
Q (m3/s)		4.17E-06	4.1E-06	4.2E-06	3.97E-06	0.000004	0.000004		0.000004	0.000004	0.000004	0.000004	3.97E-06	3.93E-06	3.9E-06	3.87E-06	3.87E-06	0.000004	4.1E-06	4.07E-06	4.07E-06	0.000004	3.93E-06	3.87E-06
i (Point 1-4)		0.03	0.02	0.02	0.03	0.01	0.02		0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.06	0.05	0.06	0.06	0.07	0.08	0.10
i (Point 1-9)		0.05	0.05	0.05	0.05	0.05	0.05		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.09	0.10	0.12
i (Point 6-9)		0.06	0.07	0.07	0.07	0.07	0.06		0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.11	0.11	0.14
K (m/s)																								
(Point 1-4)		1.4E-02	1.8E-02	1.9E-02	1.3E-02	2.7E-02	1.8E-02		1.8E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02	1.3E-02	1.0E-02	6.7E-03	7.9E-03	6.9E-03	6.1E-03	5.4E-03	4.8E-03	3.7E-03
(Point 1-9)		8.8E-03	8.3E-03	8.5E-03	7.6E-03	7.7E-03	8.1E-03		8.1E-03	7.7E-03	7.7E-03	7.7E-03	7.3E-03	7.2E-03	6.9E-03	6.6E-03	6.6E-03	5.6E-03	5.8E-03	5.4E-03	5.1E-03	4.3E-03	4.0E-03	3.1E-03
(Point 6-9)		6.2E-03	5.5E-03	5.7E-03	5.3E-03	5.4E-03	6.0E-03		6.0E-03	5.4E-03	5.4E-03	5.4E-03	5.3E-03	5.3E-03	5.3E-03	4.7E-03	4.7E-03	4.5E-03	4.6E-03	4.6E-03	4.2E-03	3.6E-03	3.5E-03	2.7E-03
% of Ko (1-3)	Ko =																							
% of Ko (1-4)	Ko =					1.8E-02		1.00	1.00	0.75	0.75	0.75	0.74	0.74	0.73	0.72	0.58	0.37	0.44	0.38	0.34	0.30	0.27	0.21
% of Ko (1-9)	Ko =					8.1E-03		1.00	1.00	0.95	0.95	0.95	0.91	0.90	0.85	0.81	0.81	0.70	0.72	0.67	0.63	0.54	0.49	0.38
% of Ko (6-9)	Ko =					6.0E-03		1.00	1.00	0.90	0.90	0.90	0.89	0.89	0.88	0.79	0.79	0.75	0.77	0.76	0.70	0.60	0.59	0.46

									65 L	
									0.186 L/min	
90.3	128.7	133.5	180.4	185.9	235.8	241.6	262.2	275.4	282.4	290.6
380	551	573	792	818	1065	1095	1199	1264	1298	1339
85.2	121.5	126.0	170.3	175.5	222.5	228.0	247.4	260.0	266.5	274.3
115	110	108	106	105	97	96	102	102	102	98
30	30	30	30	30	30	30	30	30	30	30
15	15	15	15	15	15	15	15	15	15	15
55	55	55	55	55	55	55	55	55	55	55
31.4	32.2	32.2	33.0	33.1	34.0	34.0	34.0	34.4	34.4	34.3
30.6	31.4	31.4	32.1	32.1	32.8	32.7	32.8	33.0	33.0	33.0
29.7	30.1	30.1	30.5	30.6	30.9	30.9	30.9	31.0	31.0	31.0
28.7	28.9	28.9	29.0	29.0	29.1	29.0	29.1	29.1	29.2	29.1
28	28	28	28	28	28	28	28	28	28	28
750	870	962	1100.0							
3.83E-06	3.67E-06	3.6E-06	3.53E-06	3.5E-06	3.23E-06	3.2E-06	3.4E-06	3.4E-06	3.4E-06	3.27E-06
0.11	0.11	0.12	0.14	0.14	0.18	0.19	0.18	0.20	0.20	0.19
0.12	0.15	0.15	0.18	0.19	0.23	0.23	0.23	0.24	0.24	0.24
0.14	0.17	0.18	0.22	0.23	0.26	0.26	0.26	0.27	0.26	0.27
3.4E-03	3.1E-03	2.9E-03	2.5E-03	2.4E-03	1.7E-03	1.7E-03	1.8E-03	1.6E-03	1.6E-03	1.6E-03
3.0E-03	2.4E-03	2.3E-03	1.8E-03	1.8E-03	1.4E-03	1.4E-03	1.5E-03	1.4E-03	1.4E-03	1.3E-03
2.6E-03	2.1E-03	1.9E-03	1.5E-03	1.5E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03
0.19	0.17	0.16	0.14	0.13	0.10	0.09	0.10	0.09	0.09	0.09
0.37	0.30	0.28	0.23	0.22	0.17	0.17	0.18	0.17	0.17	0.16
0.43	0.34	0.32	0.26	0.25	0.20	0.19	0.21	0.20	0.21	0.19

349.4624				491 grams			660			
5.824373							49500			
312.0	339.7	374.6	434.4	490.5	507.4	511.7	521.0	521.6	522.1	522.7
								Water		
1449	1593	1779	2114	2455	2543	2562	2603	2606	2608	2611
294.5	320.6	353.6	410.0	463.0	479.0	483.0	491.7	492.3	492.8	493.4
97	95	93	128	119	113	113	112	107	108	109
30	30	30	45	45	30	30	30	30	30	30
15	15	15	15	15	15	15	15	15	15	15
55	55	55	55	55	55	55	55	55	55	55
34.8	35.3	36.0	37.5	38.8	31.4	31.4	31.7	31.4	31.2	31.1
33.2	33.7	34.1	35.0	35.8	30.6	30.1	30.8	30.6	30.4	30.3
31.1	31.4	31.5	32.0	32.3	29.7	29.7	29.8	29.7	29.5	29.5
29.1	29.2	29.2	29.3	29.3	28.8	28.8	28.8	28.7	28.6	28.6
28	28	28	28	28	28	28	28	28	28	28
								1100	202	100
3.23E-06	3.17E-06	3.1E-06	2.84E-06	2.64E-06	3.77E-06	3.77E-06	3.73E-06	3.57E-06	3.6E-06	3.63E-06
0.23	0.24	0.28	0.35	0.44	0.11	0.19	0.13	0.11	0.11	0.11
0.26	0.28	0.31	0.37	0.43	0.12	0.12	0.13	0.12	0.12	0.11
0.29	0.32	0.34	0.39	0.44	0.13	0.14	0.15	0.14	0.13	0.13
1.4E-03	1.3E-03	1.1E-03	7.8E-04	5.8E-04	3.2E-03	2.0E-03	2.8E-03	3.0E-03	3.0E-03	3.1E-03
1.2E-03	1.1E-03	9.6E-04	7.3E-04	5.9E-04	3.1E-03	3.0E-03	2.7E-03	2.9E-03	3.0E-03	3.1E-03
1.1E-03	9.5E-04	8.9E-04	7.1E-04	5.8E-04	2.8E-03	2.7E-03	2.4E-03	2.4E-03	2.7E-03	2.7E-03
0.08	0.07	0.06	0.04	0.03	0.18	0.11	0.16	0.17	0.17	0.17
0.15	0.14	0.12	0.09	0.07	0.39	0.37	0.33	0.35	0.37	0.38
0.18	0.16	0.15	0.12	0.10	0.47	0.45	0.40	0.40	0.45	0.45

Bumped table - extremely cloudy fines exiting sample, k jumped.

Constant HeadTest

min ml s
ml s min

Date 05-Jun-07
Water Properties (T= 20C)

Sand Unimin uniform sand A (m2) 0.01039
γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.5% (kaolinite)

																			50.6	55.3	61.9	65.5	66.0	66.4
																							Brine	
Time after beginning flow with suspension of fines (min)																								
	Elevation	Water	Water	Water	Water	Water	Water	0	3	6	9	14	22	30	47	82	131	158	211	232	262	278	280	282
Pore volumes								0	0.7	1.4	2.1	3.2	5.1	6.9	10.8	18.9	30.1	36.2	47.7	52.2	58.5	61.9	62.3	62.7
Flow Rate Readings																								
Volume collected (mL)		118	121	122	121	121			122	122	123	122	123	122	122	121	121	118	113	111	112	112	111	117
Time taken to collect (s)		30	30	30	30	30	60		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																								
Point 1 (cm)	1.5	30	29.9	29.8	29.7	30			30.2	30.6	30.6	30.7	30.8	30.9	31.0	31.3	31.7	31.9	32.3	32.6	32.9	33.1	33.2	32.0
Point 2 (cm)	3																							
Point 3 (cm)	4.5																							
Point 4 (cm)	8.5	29.8	29.8	29.7	29.6	29.9			30.0	30.3	30.4	30.5	30.5	30.6	30.6	30.8	31.1	31.2	31.4	31.5	31.8	31.9	32.6	31.5
Point 5 (cm)	12.5																							
Point 6 (cm)	16.5	29.4	29.4	29.3	29.2	29.5			29.5	29.7	29.8	29.8	29.8	29.9	30.0	30.1	30.2	30.2	30.3	30.3	30.4	30.4	31.3	30.6
Point 7 (cm)	20.5																							
Point 8 (cm)	22																							
Point 9 (cm)	23.5	28.8	28.8	28.8	28.7	28.95			29.0	29.1	29.1	29.1	29.2	29.2	29.3	29.3	29.4	29.4	29.4	29.4	29.4	29.4	29.7	29.5
			4.033333	mL/s	4.03E-06																			
			1000	mL/L				Turb.	3	482	574	958	1100											
Calculations			1000	L/m^3																				
Q (m3/s)		3.93E-06	4.03E-06	4.07E-06	4.03E-06	4.03E-06	0		4.067E-06	4.067E-06	0.0000041	4.067E-06	0.0000041	4.067E-06	4.067E-06	4.033E-06	4.033E-06	3.933E-06	3.767E-06	0.0000037	3.73E-06	3.73E-06	3.7E-06	3.9E-06
i (Point 1-3)		10.00	9.97	9.93	9.90	10.00	0.00		10.07	10.20	10.20	10.23	10.27	10.30	10.33	10.42	10.55	10.62	10.77	10.85	10.95	11.03	11.07	10.65
i (Point 1-4)		0.03	0.01	0.01	0.01	0.01	0.00		0.03	0.04	0.03	0.03	0.04	0.04	0.06	0.06	0.08	0.09	0.13	0.15	0.15	0.17	0.09	0.06
i (Point 1-9)		0.05	0.05	0.05	0.05	0.05	0.00		0.06	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.10	0.11	0.13	0.15	0.16	0.17	0.16	0.11
i (Point 6-9)		0.09	0.09	0.07	0.07	0.08	0.00		0.08	0.09	0.10	0.10	0.09	0.10	0.11	0.11	0.11	0.12	0.14	0.14	0.15	0.15	0.23	0.16
i (Point 3-6)		-2.45	-2.45	-2.44	-2.43	-2.46	0.00		-2.46	-2.48	-2.48	-2.48	-2.48	-2.49	-2.50	-2.51	-2.51	-2.52	-2.53	-2.53	-2.53	-2.53	-2.61	-2.55
i (Point 4-7)		2.48	2.48	2.48	2.47	2.49	0.00		2.50	2.53	2.53	2.54	2.54	2.55	2.55	2.57	2.59	2.60	2.62	2.63	2.65	2.66	2.72	2.63
K (m/s)																								
(Point 1-3)		3.8E-05	3.9E-05	3.9E-05	3.9E-05	3.9E-05	#DIV/0!		3.9E-05	3.8E-05	3.9E-05	3.8E-05	3.8E-05	3.8E-05	3.8E-05	3.7E-05	3.7E-05	3.6E-05	3.4E-05	3.3E-05	3.3E-05	3.3E-05	3.2E-05	3.5E-05
(Point 1-4)		1.3E-02	2.7E-02	2.7E-02	2.7E-02	2.7E-02	#DIV/0!		1.4E-02	9.1E-03	1.4E-02	1.4E-02	9.2E-03	9.1E-03	6.9E-03	6.0E-03	4.9E-03	4.1E-03	2.8E-03	2.4E-03	2.4E-03	2.1E-03	4.2E-03	5.8E-03
(Point 1-9)		6.9E-03	7.8E-03	8.6E-03	8.5E-03	8.1E-03	#DIV/0!		6.9E-03	5.7E-03	5.8E-03	5.4E-03	5.4E-03	5.1E-03	4.9E-03	4.4E-03	3.7E-03	3.3E-03	2.7E-03	2.4E-03	2.3E-03	2.1E-03	2.2E-03	3.3E-03
(Point 6-9)		4.4E-03	4.5E-03	5.5E-03	5.4E-03	4.9E-03	#DIV/0!		5.0E-03	4.6E-03	3.9E-03	3.9E-03	4.6E-03	3.9E-03	3.7E-03	3.4E-03	3.4E-03	3.1E-03	2.7E-03	2.6E-03	2.4E-03	2.4E-03	1.6E-03	2.3E-03
(Point 3-6)		-1.5E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	#DIV/0!		-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.5E-04
(Point 4-7)		1.5E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	#DIV/0!		1.6E-04	1.6E-04	1.6E-04	1.5E-04	1.6E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.4E-04
% of Ko (1-3)	Ko =																							
% of Ko (1-4)	Ko =					2.7E-02		1.00	0.50	0.34	0.51	0.50	0.34	0.34	0.25	0.22	0.18	0.15	0.10	0.09	0.09	0.08	0.15	0.21
% of Ko (1-9)	Ko =					8.1E-03		1.00	0.85	0.71	0.71	0.66	0.67	0.62	0.60	0.54	0.46	0.41	0.33	0.30	0.28	0.26	0.28	0.41
% of Ko (6-9)	Ko =					4.9E-03		1.00	1.01	0.92	0.80	0.79	0.93	0.79	0.74	0.69	0.69	0.63	0.54	0.53	0.48	0.48	0.32	0.46
						3.3E-03																		

																		660							
																		49500							
66.9	67.4	68.1	69.0	70.6	74.4	80.9	87.0	96.9	105.1	115.5	129.4	141.0	154.0	163.4	173.2	192.3	197.1	208.2	210.9	217.7	225.1	230.0	230.2	230.9	231.4
				5.0																			Water		
284	286	289	293	300	316	344	370	412	447	491	550	599	654	694	736	820	841	891	903	934	968	990	991	994	996
63.1	63.6	64.2	65.1	66.7	70.2	76.4	82.1	91.4	99.2	109.0	122.1	133.1	145.4	154.3	163.5	181.5	186.0	196.5	199.0	205.4	212.5	217.1	217.3	218.0	218.4
117	117	117	117	117	117	117	117	117	118	118	118	119	118	117	115	113	113	110	110	109	111	111	117	112	113
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
31.8	31.8	31.8	31.8	31.8	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	32.1	32.1	32.1	32.0	32.0	32.3	31.9	31.7
31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.8	31.4	31.2
30.4	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.7	30.5	30.3
29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.3	29.3	29.3	29.3	29.3	29.3	29.3	29.4	29.3	29.2
1100	295	18.1	10.0	6.1	4.2						2.4			3.7		1.7						5.5	1100	43.5	51.3
3.9E-06	3.9E-06	3.9E-06	3.9E-06	3.9E-06	3.9E-06	3.9E-06	3.9E-06	3.9E-06	3.93E-06	3.93E-06	3.93E-06	3.97E-06	3.93E-06	3.9E-06	3.83E-06	3.77E-06	3.77E-06	3.67E-06	3.67E-06	3.63E-06	3.7E-06	3.7E-06	3.9E-06	3.73E-06	3.77E-06
10.60	10.60	10.60	10.60	10.60	10.62	10.62	10.62	10.62	10.62	10.63	10.63	10.62	10.62	10.63	10.62	10.63	10.63	10.68	10.70	10.70	10.67	10.67	10.77	10.63	10.55
0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.09	0.09	0.08	0.08	0.08	0.07	0.06
0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.11
0.14	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.18	0.17	0.17	0.19	0.17	0.16
-2.53	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.54	-2.55	-2.54	-2.53
2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.63	2.62	2.63	2.63	2.62	2.62	2.63	2.62	2.63	2.63	2.63	2.63	2.63	2.62	2.62	2.65	2.62	2.60
3.5E-05	3.5E-05	3.5E-05	3.5E-05	3.5E-05	3.5E-05	3.5E-05	3.5E-05	3.5E-05	3.6E-05	3.6E-05	3.6E-05	3.6E-05	3.6E-05	3.5E-05	3.5E-05	3.4E-05	3.4E-05	3.3E-05	3.3E-05	3.3E-05	3.3E-05	3.3E-05	3.5E-05	3.4E-05	3.4E-05
6.6E-03	6.6E-03	6.6E-03	6.6E-03	6.6E-03	5.8E-03	5.8E-03	6.6E-03	7.5E-03	6.6E-03	6.6E-03	6.6E-03	6.7E-03	6.6E-03	6.6E-03	6.5E-03	6.3E-03	6.3E-03	4.5E-03	4.1E-03	4.1E-03	4.5E-03	4.5E-03	4.8E-03	5.0E-03	5.6E-03
3.4E-03	3.4E-03	3.4E-03	3.4E-03	3.4E-03	3.3E-03	3.3E-03	3.4E-03	3.4E-03	3.4E-03	3.3E-03	3.3E-03	3.4E-03	3.3E-03	3.2E-03	3.2E-03	3.1E-03	3.1E-03	2.8E-03	2.8E-03	2.7E-03	2.8E-03	2.8E-03	2.8E-03	3.0E-03	3.3E-03
2.6E-03	2.3E-03	2.3E-03	2.3E-03	2.3E-03	2.3E-03	2.3E-03	2.4E-03	2.4E-03	2.4E-03	2.4E-03	2.4E-03	2.4E-03	2.3E-03	2.3E-03	2.2E-03	2.2E-03	2.2E-03	2.1E-03	2.1E-03	2.0E-03	2.1E-03	2.1E-03	2.0E-03	2.1E-03	2.3E-03
-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.5E-04	-1.4E-04	-1.4E-04
1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04
0.24	0.24	0.24	0.24	0.24	0.21	0.21	0.24	0.28	0.24	0.24	0.24	0.25	0.24	0.24	0.24	0.23	0.23	0.17	0.15	0.15	0.17	0.17	0.18	0.19	0.21
0.42	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.41	0.41	0.42	0.41	0.40	0.40	0.38	0.38	0.35	0.34	0.33	0.35	0.35	0.34	0.37	0.40
0.53	0.46	0.46	0.46	0.46	0.46	0.46	0.48	0.48	0.49	0.49	0.49	0.49	0.47	0.46	0.45	0.45	0.45	0.43	0.42	0.40	0.42	0.42	0.41	0.42	0.47

															87.7
232.3	233.0	233.6	235.2	237.5	239.7	243.3	247.1	253.3	258.4	265.1	277.9	286.8	300.9	309.1	317.7
1000	1003	1006	1013	1023	1033	1049	1066	1094	1117	1148	1207	1248	1312	1348	1386
219.2	219.9	220.5	222.0	224.1	226.3	229.7	233.3	239.1	243.9	250.3	262.3	270.7	284.1	291.7	299.8
112	113	113	113	112	112	113	112	110	109	109	108	108	113	113	113
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
31.6	31.5	31.5	31.5	31.5	31.6	31.4	31.4	31.4	31.5	31.5	31.5	31.5	31.6	31.7	31.7
31.1	31.1	31.1	31.1	31.1	31.1	31.0	31.0	31.0	31.0	31.1	31.0	31.0	31.1	31.1	31.2
30.2	30.2	30.2	30.2	30.1	30.2	30.0	30.0	30.0	30.1	30.1	30.1	30.0	30.1	30.2	30.2
29.2	29.2	29.2	29.2	29.1	29.1	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
21.6	14.4	10.2	12.3	5.6	6.1	37.4	5.9		3.7				6.0		
3.73E-06	3.77E-06	3.77E-06	3.77E-06	3.73E-06	3.73E-06	3.77E-06	3.73E-06	3.67E-06	3.63E-06	3.63E-06	3.6E-06	3.6E-06	3.77E-06	3.77E-06	3.77E-06
10.52	10.50	10.50	10.50	10.50	10.52	10.47	10.47	10.47	10.50	10.50	10.48	10.48	10.53	10.55	10.57
0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.07	0.06	0.07	0.06	0.07	0.08	0.08
0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12
0.15	0.15	0.15	0.14	0.14	0.16	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.16	0.16	0.16
-2.52	-2.52	-2.52	-2.51	-2.51	-2.51	-2.50	-2.50	-2.50	-2.51	-2.51	-2.51	-2.50	-2.51	-2.51	-2.51
2.59	2.59	2.59	2.59	2.59	2.59	2.58	2.58	2.58	2.58	2.59	2.58	2.58	2.59	2.59	2.60
3.4E-05	3.5E-05	3.5E-05	3.5E-05	3.4E-05	3.4E-05	3.5E-05	3.4E-05	3.4E-05	3.3E-05	3.3E-05	3.3E-05	3.3E-05	3.4E-05	3.4E-05	3.4E-05
5.6E-03	6.3E-03	6.3E-03	6.3E-03	5.6E-03	5.0E-03	5.6E-03	5.6E-03	5.5E-03	4.9E-03	5.4E-03	4.9E-03	5.4E-03	5.1E-03	4.6E-03	4.6E-03
3.3E-03	3.4E-03	3.4E-03	3.4E-03	3.3E-03	3.2E-03	3.3E-03	3.2E-03	3.2E-03	3.1E-03	3.1E-03	3.0E-03	3.0E-03	3.1E-03	3.0E-03	3.0E-03
2.4E-03	2.4E-03	2.4E-03	2.5E-03	2.5E-03	2.3E-03	2.5E-03	2.4E-03	2.4E-03	2.2E-03	2.2E-03	2.1E-03	2.3E-03	2.3E-03	2.2E-03	2.2E-03
-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.5E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04
1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04
0.21	0.23	0.23	0.23	0.21	0.19	0.21	0.21	0.20	0.18	0.20	0.18	0.20	0.19	0.17	0.17
0.40	0.42	0.42	0.42	0.40	0.39	0.41	0.40	0.39	0.38	0.38	0.37	0.37	0.38	0.37	0.36
0.48	0.49	0.49	0.51	0.51	0.46	0.51	0.48	0.48	0.45	0.45	0.43	0.47	0.47	0.45	0.45

Constant HeadTest

Date	29-May-07																							
Sand	Unimin uniform sand			A (m2)	0.01039				1.4	3.4	5.0	6.7	8.6	10.1	11.8	13.7	15.8	17.9	24.2	30.7	38.4	45.6	58.4	65.8
Clay in suspension	0.5% (kaolinite)								0.1	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.3	1.7	2.2	2.7	3.2	4.2	4.7
	Time after beginning flow with suspension of fines (min)																							
	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	6	14	21	28	36	42	49	57	66	75	102	130	163	194	249	281
Pore volumes								0	1.4	3.2	4.8	6.3	8.2	9.5	11.1	12.9	14.9	16.9	22.8	29.0	36.2	43.0	55.1	62.1
Flow Rate Readings																								
Volume collected (mL)		121	120	120	111	111			120	121	119	120	120	120	120	119	117	117	116	116	117	116	116	116
Time taken to collect (s)		30	30	30	60	60	60		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																								
Point 1 (cm)	1.5	30	30.6	30.7					30.8	30.9	31.0	31.0	31.0	31.1	31.1	31.2	31.2	31.2	31.4	31.4	31.6	31.9	32.1	32.4
Point 2 (cm)	3																							
Point 3 (cm)	4.5																							
Point 4 (cm)	8.5	29.8	30.2	30.3					30.3	30.3	30.4	30.4	30.4	30.4	30.5	30.5	30.5	30.5	30.6	30.6	30.7	30.7	30.9	31.0
Point 5 (cm)	12.5																							
Point 6 (cm)	16.5	29.4	29.8	29.8					29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.9	29.9	29.9	29.9	30.0	30.0
Point 7 (cm)	20.5																							
Point 8 (cm)	22																							
Point 9 (cm)	23.5	28.8	29.1	28.9					29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	28.9	29.0	29.0	28.9	29.0	29.0
			4	mL/s	0.000004																			
			1000	mL/L				Turb.	164	250	183	203	92	138	1100									
Calculations			1000	L/m^3																				
Q (m3/s)		4.03E-06	0.000004	0.000004	1.85E-06	1.85E-06	0		0.000004	4.03E-06	3.97E-06	0.000004	0.000004	0.000004	0.000004	3.97E-06	3.9E-06	3.9E-06	3.87E-06	3.87E-06	3.9E-06	3.87E-06	3.87E-06	3.87E-06
i (Point 1-3)		10.00	10.20	10.23	0.00	0.00	0.00		10.27	10.30	10.33	10.33	10.33	10.37	10.37	10.40	10.40	10.40	10.47	10.47	10.53	10.63	10.70	10.80
i (Point 1-4)		0.03	0.06	0.06	0.00	0.00	0.00		0.07	0.09	0.09	0.09	0.09	0.10	0.09	0.10	0.10	0.10	0.11	0.11	0.13	0.17	0.17	0.20
i (Point 1-9)		0.05	0.07	0.08	0.00	0.00	0.00		0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.12	0.14	0.14	0.15
i (Point 6-9)		0.09	0.10	0.13	0.00	0.00	0.00		0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.14	0.13	0.13	0.14	0.14	0.14
i (Point 3-6)		-2.45	-2.48	-2.48	0.00	0.00	0.00		-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.49	-2.49	-2.49	-2.49	-2.50	-2.50
i (Point 4-7)		2.48	2.52	2.53	0.00	0.00	0.00		2.53	2.53	2.53	2.53	2.53	2.53	2.54	2.54	2.54	2.54	2.55	2.55	2.56	2.56	2.58	2.58
K (m/s)																								
(Point 1-3)		3.9E-05	3.8E-05	3.8E-05	#DIV/0!	#DIV/0!	#DIV/0!		3.8E-05	3.8E-05	3.7E-05	3.7E-05	3.7E-05	3.7E-05	3.7E-05	3.7E-05	3.6E-05	3.6E-05	3.6E-05	3.6E-05	3.6E-05	3.5E-05	3.5E-05	3.4E-05
(Point 1-4)		1.4E-02	6.7E-03	6.7E-03	#DIV/0!	#DIV/0!	#DIV/0!		5.4E-03	4.5E-03	4.5E-03	4.5E-03	4.5E-03	3.9E-03	4.5E-03	3.8E-03	3.8E-03	3.8E-03	3.3E-03	3.3E-03	2.9E-03	2.2E-03	2.2E-03	1.9E-03
(Point 1-9)		7.1E-03	5.6E-03	4.7E-03	#DIV/0!	#DIV/0!	#DIV/0!		4.7E-03	4.5E-03	4.2E-03	4.2E-03	4.2E-03	4.0E-03	4.0E-03	3.8E-03	3.8E-03	3.8E-03	3.3E-03	3.4E-03	3.2E-03	2.7E-03	2.6E-03	2.4E-03
(Point 6-9)		4.5E-03	3.9E-03	3.0E-03	#DIV/0!	#DIV/0!	#DIV/0!		3.4E-03	3.4E-03	3.3E-03	3.4E-03	3.4E-03	3.4E-03	3.4E-03	3.3E-03	3.3E-03	3.3E-03	2.6E-03	2.9E-03	2.9E-03	2.6E-03	2.6E-03	2.6E-03
(Point 3-6)		-1.6E-04	-1.6E-04	-1.6E-04	#DIV/0!	#DIV/0!	#DIV/0!		-1.6E-04	-1.6E-04	-1.5E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04
(Point 4-7)		1.6E-04	1.5E-04	1.5E-04	#DIV/0!	#DIV/0!	#DIV/0!		1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04
% of Ko (1-3)	Ko =																							
% of Ko (1-4)	Ko =					6.7E-03		1.00	0.80	0.67	0.66	0.67	0.67	0.57	0.67	0.57	0.56	0.56	0.48	0.48	0.43	0.32	0.32	0.28
% of Ko (1-9)	Ko =					4.7E-03		1.00	1.00	0.96	0.89	0.90	0.90	0.86	0.86	0.81	0.80	0.80	0.70	0.73	0.68	0.58	0.56	0.51
% of Ko (6-9)	Ko =					3.9E-03		1.00	0.87	0.88	0.87	0.87	0.87	0.87	0.87	0.87	0.85	0.85	0.68	0.75	0.76	0.68	0.68	0.68

																		660							
																		49500							
73.4	80.1	87.5	94.4	100.8																					
5.2	5.7	6.3	6.8	7.3	Brine																		Water		
314	343	376	407	436	438	443	449	455	461	466	477	487	496	506	517	547	581	611	642	702	755	808	932	938	945
69.3	75.6	82.6	89.1	95.2	95.6	96.6	97.9	99.1	100.4	101.4	103.7	105.7	107.5	109.6	111.9	118.1	125.1	131.3	137.7	149.8	160.4	171.0	195.2	196.4	197.8
115	114	112	111	110	112	110	110	111	110	110	106	109	109	109	109	110	110	109	108	106	105	107	100	110	108
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
32.4	32.5	32.5	32.9	32.9	32.9	32.8	32.9	32.9	32.9	32.9	33.0	33.0	33.0	33.1	33.1	33.2	33.2	33.5	33.5	33.6	33.7	34.0	33.4	33.4	33.2
31.0	31.1	31.1	31.4	31.4	31.4	31.4	31.4	31.4	331.4	31.4	31.4	31.4	31.5	31.5	31.5	31.5	31.5	31.6	31.7	32.0	32.0	32.1	32.0	31.5	31.5
30.0	30.0	30.0	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.3	30.3	30.3	30.3	30.4	30.4	30.5	30.2	30.1
28.9	28.9	28.9	28.9	28.9	29.8	29.8	29.9	29.9	29.9	29.9	29.8	29.8	29.8	29.8	29.9	29.9	29.8	29.8	29.8	29.8	29.9	29.9	29.2	29.0	29.0
					1100.0	69.0	35.9	24.1	16.4	14.0	16.0	15.6	11.0	11.6	9.7	8.0	54.2	21.0	129.0	282.5	32.0	31.3	599	47.3	17.6
3.83E-06	3.8E-06	3.73E-06	3.7E-06	3.67E-06	3.73E-06	3.67E-06	3.67E-06	3.7E-06	3.67E-06	3.67E-06	3.53E-06	3.63E-06	3.63E-06	3.63E-06	3.63E-06	3.67E-06	3.67E-06	3.63E-06	3.6E-06	3.53E-06	3.5E-06	3.57E-06	3.33E-06	3.67E-06	3.6E-06
10.80	10.83	10.83	10.97	10.97	10.97	10.93	10.97	10.97	10.97	10.97	11.00	11.00	11.00	11.03	11.03	11.07	11.07	11.17	11.17	11.20	11.23	11.33	11.13	11.13	11.07
0.20	0.20	0.20	0.21	0.21	0.21	0.20	0.21	0.21	-42.64	0.21	0.23	0.23	0.21	0.23	0.23	0.24	0.24	0.27	0.26	0.23	0.24	0.27	0.20	0.27	0.24
0.16	0.16	0.16	0.18	0.18	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.17	0.17	0.17	0.17	0.19	0.19	0.20	0.19
0.16	0.16	0.16	0.19	0.19	0.06	0.06	0.04	0.04	0.04	0.04	0.06	0.06	0.06	0.06	0.04	0.04	0.07	0.07	0.07	0.07	0.07	0.07	0.19	0.17	0.16
-2.50	-2.50	-2.50	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.53	-2.53	-2.53	-2.53	-2.53	-2.53	-2.54	-2.52	-2.51
2.58	2.59	2.59	2.62	2.62	2.62	2.62	2.62	2.62	27.62	2.62	2.62	2.62	2.63	2.63	2.63	2.63	2.63	2.63	2.64	2.67	2.67	2.68	2.67	2.63	2.63
3.4E-05	3.4E-05	3.3E-05	3.2E-05	3.2E-05	3.3E-05	3.2E-05	3.2E-05	3.2E-05	3.2E-05	3.2E-05	3.1E-05	3.2E-05	3.2E-05	3.2E-05	3.2E-05	3.2E-05	3.2E-05	3.1E-05	3.1E-05	3.0E-05	3.0E-05	3.0E-05	2.9E-05	3.2E-05	3.1E-05
1.8E-03	1.8E-03	1.8E-03	1.7E-03	1.6E-03	1.7E-03	1.8E-03	1.6E-03	1.7E-03	-8.3E-06	1.6E-03	1.5E-03	1.5E-03	1.6E-03	1.5E-03	1.5E-03	1.5E-03	1.5E-03	1.3E-03	1.3E-03	1.5E-03	1.4E-03	1.3E-03	1.6E-03	1.3E-03	1.4E-03
2.3E-03	2.2E-03	2.2E-03	2.0E-03	1.9E-03	2.6E-03	2.6E-03	2.6E-03	2.6E-03	2.6E-03	2.6E-03	2.3E-03	2.4E-03	2.4E-03	2.3E-03	2.4E-03	2.4E-03	2.3E-03	2.1E-03	2.1E-03	2.0E-03	2.0E-03	1.8E-03	1.7E-03	1.8E-03	1.8E-03
2.3E-03	2.3E-03	2.3E-03	1.9E-03	1.9E-03	6.3E-03	6.2E-03	8.2E-03	8.3E-03	8.2E-03	8.2E-03	6.0E-03	6.1E-03	6.1E-03	6.1E-03	8.2E-03	8.2E-03	4.9E-03	4.9E-03	4.9E-03	4.8E-03	4.7E-03	4.8E-03	1.7E-03	2.1E-03	2.2E-03
-1.5E-04	-1.5E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.3E-04	-1.3E-04	-1.4E-04	-1.3E-04	-1.4E-04	-1.4E-04
1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.4E-04	1.3E-04	1.3E-04	1.4E-04	1.3E-05	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.2E-04	1.3E-04	1.3E-04
0.27	0.27	0.27	0.25	0.24	0.25	0.26	0.24	0.25	0.00	0.24	0.22	0.23	0.24	0.23	0.23	0.22	0.22	0.19	0.20	0.22	0.21	0.19	0.24	0.19	0.21
0.49	0.48	0.47	0.42	0.41	0.54	0.55	0.55	0.56	0.55	0.55	0.50	0.51	0.51	0.50	0.51	0.50	0.49	0.44	0.44	0.42	0.41	0.39	0.36	0.38	0.39
0.61	0.60	0.59	0.50	0.49	1.63	1.60	2.14	2.16	2.14	2.14	1.55	1.59	1.59	1.59	2.12	2.14	1.28	1.27	1.26	1.24	1.23	1.25	0.45	0.53	0.57

412.5 litres
31.1 hours

Brine

953	961	991	1023	1059	1093	1150	1213	1274	1334	1394	1399	1529	1594	1654	1715	1778	1837	1866
199.4	201.0	207.1	213.5	220.6	227.4	239.0	251.9	264.5	276.6	288.8	289.8	316.4	330.3	343.4	356.8	370.5	383.1	389.4
107	105	108	105	105	107	108	109	109	106	108	107	110	116	116	116	115	112	115
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
33.3	33.4	33.4	33.4	33.4	33.5	33.5	33.6	33.7	33.7	33.9	32.6	32.5	32.6	32.7	32.8	32.9	32.9	32.8
31.5	31.5	31.5	31.6	31.7	31.8	31.9	31.9	31.9	31.9	32.0	30.5	30.6	30.6	30.5	30.6	30.6	30.6	30.6
30.1	30.1	30.2	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3	29.3	29.4	29.4	29.3	29.3	29.3	29.3	29.2
29.0	29.6	30.3	30.3	30.3	30.3	30.5	30.0	30.4	30.8	31.0	28.7	28.7	28.7	28.5	28.5	28.4	28.4	28.4
8.2	8.8	6.7	4.4	4.7	4.5	47.0	31.0	141	18.0	17.4	83	25.6	4.2	36.0	16.5	5.4	9.4	2.3
3.57E-06	3.5E-06	3.6E-06	3.5E-06	3.5E-06	3.57E-06	3.6E-06	3.63E-06	3.63E-06	3.53E-06	3.6E-06	3.57E-06	3.67E-06	3.87E-06	3.87E-06	3.87E-06	3.83E-06	3.73E-06	3.83E-06
11.10	11.13	11.13	11.13	11.13	11.17	11.17	11.20	11.23	11.23	11.30	10.87	10.83	10.87	10.90	10.93	10.97	10.97	10.93
0.26	0.27	0.27	0.26	0.24	0.24	0.23	0.24	0.26	0.26	0.27	0.30	0.27	0.29	0.31	0.31	0.33	0.33	0.31
0.20	0.17	0.14	0.14	0.14	0.15	0.14	0.16	0.15	0.13	0.13	0.18	0.17	0.18	0.19	0.20	0.20	0.20	0.20
0.16	0.07	-0.01	0.00	0.00	0.00	-0.03	0.04	-0.01	-0.07	-0.10	0.09	0.10	0.10	0.11	0.11	0.13	0.13	0.11
-2.51	-2.51	-2.52	-2.53	-2.53	-2.53	-2.53	-2.53	-2.53	-2.53	-2.53	-2.44	-2.45	-2.45	-2.44	-2.44	-2.44	-2.44	-2.43
2.63	2.63	2.63	2.63	2.64	2.65	2.66	2.66	2.66	2.66	2.67	2.54	2.55	2.55	2.54	2.55	2.55	2.55	2.55
3.1E-05	3.0E-05	3.1E-05	3.0E-05	3.0E-05	3.1E-05	3.1E-05	3.1E-05	3.1E-05	3.0E-05	3.1E-05	3.2E-05	3.3E-05	3.4E-05	3.4E-05	3.4E-05	3.4E-05	3.3E-05	3.4E-05
1.3E-03	1.2E-03	1.3E-03	1.3E-03	1.4E-03	1.4E-03	1.5E-03	1.4E-03	1.4E-03	1.3E-03	1.3E-03	1.1E-03	1.3E-03	1.3E-03	1.2E-03	1.2E-03	1.1E-03	1.1E-03	1.2E-03
1.8E-03	2.0E-03	2.5E-03	2.4E-03	2.4E-03	2.4E-03	2.5E-03	2.1E-03	2.3E-03	2.6E-03	2.6E-03	1.9E-03	2.0E-03	2.1E-03	1.9E-03	1.9E-03	1.8E-03	1.8E-03	1.8E-03
2.2E-03	4.7E-03	-2.4E-02	#DIV/0!	#DIV/0!	#DIV/0!	-1.2E-02	8.2E-03	-2.4E-02	-4.8E-03	-3.5E-03	4.0E-03	3.5E-03	3.7E-03	3.3E-03	3.3E-03	2.9E-03	2.8E-03	3.2E-03
-1.4E-04	-1.3E-04	-1.4E-04	-1.3E-04	-1.3E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.3E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04	-1.5E-04
1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.4E-04	1.4E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04
0.20	0.18	0.19	0.19	0.21	0.21	0.22	0.21	0.20	0.20	0.19	0.17	0.19	0.19	0.18	0.18	0.17	0.16	0.17
0.37	0.41	0.52	0.51	0.51	0.50	0.54	0.45	0.50	0.55	0.56	0.41	0.43	0.45	0.41	0.40	0.38	0.37	0.39
0.57	1.23	-6.30	#DIV/0!	#DIV/0!	#DIV/0!	-3.15	2.12	-6.36	-1.24	-0.90	1.04	0.92	0.97	0.85	0.85	0.75	0.73	0.84

Uniform Sand with Battleford Till fines

Constant HeadTest min ml s

Test AO 1st setup ml s min 689 g

Date 04-Oct-07 Water Properties (T= 20C)

Sand Uniform sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 137.9 L

Clay in suspension 0.5% Batt. Till (5 g/L)

Time after beginning flow with suspension of fines (min)

		Elevation	Water	Water	Water	Water	Water	Water	0	4	13.5	30	63	120	295	481	584				
Pore volumes									0	0.9	3.1	6.9	14.5	27.7	67.9	108.8	130.1				
Volume collected (mL)			123.5	124	122.5	122.5	119	118.5		121	121.5	121.5	122	123.5	120	113	106.5				
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30				
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15				
	0	55				55				55	55	55	55	55	55	55	55				
Point 1 (cm)	1.5	4.2	29.25	29.25	29.25	29.25				29.3	29.3	29.3	29.4	29.4	29.6	30.0	30.5				
Point 4 (cm)	8.5	11.2	29	29	29	28.95				29.0	29.0	29.0	29.1	29.1	29.3	29.4	29.5				
Point 6 (cm)	16.5	19.2	28.65	28.65	28.65	28.6				28.6	28.7	28.7	28.7	28.7	28.8	28.8	28.8				
Point 9 (cm)	23.5	26.2	28.25	28.15	28.15	28.15				28.2	28.2	28.2	28.2	28.2	28.2	28.1	28.0				
	25			4.133333		28				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0				
				1000	mL/L	4.13E-06		Turb.	0	410.0	458	549	778	972	1100						
Calculations				1000	L/m^3																
Q (m3/s)			4.12E-06	4.13E-06	4.08E-06	4.08E-06	3.97E-06	3.95E-06		4.033E-06	4.05E-06	4.05E-06	4.067E-06	4.117E-06	0.000004	3.767E-06	3.55E-06				
i (Point 1-4)			0.04	0.04	0.04	0.04	0.00	0.00		0.04	0.04	0.04	0.04	0.04	0.05	0.09	0.15				
i (Point 1-9)			0.05	0.05	0.05	0.05	0.00	0.00		0.05	0.05	0.05	0.05	0.06	0.07	0.09	0.11				
i (Point 6-9)			0.06	0.07	0.07	0.06	0.00	0.00		0.06	0.07	0.07	0.07	0.07	0.09	0.10	0.11				
i (Point 4-6)			0.04	0.04	0.04	0.04	0.00	0.00		0.05	0.04	0.04	0.05	0.06	0.06	0.08	0.09				
K (m/s)																					
(Point 1-4)			1.1E-02	1.1E-02	1.1E-02	9.2E-03	#DIV/0!	#DIV/0!		1.1E-02	1.1E-02	9.1E-03	9.1E-03	9.2E-03	7.7E-03	4.2E-03	2.3E-03				
(Point 1-9)			8.7E-03	8.0E-03	7.9E-03	7.9E-03	#DIV/0!	#DIV/0!		7.8E-03	7.8E-03	7.5E-03	7.2E-03	7.0E-03	5.8E-03	4.1E-03	3.0E-03				
(Point 6-9)			6.9E-03	5.6E-03	5.5E-03	6.1E-03	#DIV/0!	#DIV/0!		6.0E-03	5.5E-03	5.5E-03	5.5E-03	5.5E-03	4.5E-03	3.6E-03	3.2E-03				
(Point 4-6)			9.1E-03	9.1E-03	9.0E-03	9.0E-03	#DIV/0!	#DIV/0!		7.8E-03	8.9E-03	8.9E-03	7.8E-03	7.0E-03	6.2E-03	4.5E-03	3.9E-03				

% of Ko (1-4)	Ko =	9.2E-03	1.00	1.19	1.19	0.99	1.00	1.01	0.84	0.46	0.25
% of Ko (1-9)	Ko =	7.9E-03	1.00	0.99	0.99	0.95	0.91	0.89	0.74	0.52	0.38
% of Ko (6-9)	Ko =	6.1E-03	1.00	0.99	0.89	0.89	0.90	0.91	0.73	0.59	0.52
% of Ko (4-6)	Ko =	9.0E-03	1.00	0.86	0.99	0.99	0.87	0.78	0.69	0.50	0.43

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines		Tare		14.57			14.35	14.46	14.41	14.26
AO-1	85.06	678.1	670.7	7.40	1.2%	2	Volume		19.10			19.75	18.95	19.35	19.60
AO-2	86.22	673.77	661.04	12.73	2.2%		Mass After		14.58			14.37	14.49	14.45	14.28
AO-3	108.26	592.3	577.89	14.41	3.0%	3	g solids		0.01			0.02	0.03	0.04	0.02
AO-4	84.44	673.29	651.53	21.76	3.7%		g salt		0.00			0.00	0.00	0.00	0.00
AO-5	81.81	677.28	657.48	19.80	3.3%		g clay		0.01			0.02	0.03	0.04	0.02
AO-6	84.85	785.86	713.33	72.53	10.3%	1	clay (g/L)		0.52			1.01	1.58	2.07	1.02
			3.9E+03												

Post-test total mass of fines 149 g 3.8E-02

Mass of fines injected 689 g

Constant HeadTest min ml s

Test S ml s min 38000 1.06 1267 grams

Date 18-Jul-07 Water Properties (T= 20C) 40280

Sand Unimin sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 253.4

Clay in suspension 0.5% (Battleford Till) 5 g/L

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2	7	13	22	31	48	68	94	158	397	685	703	921	1138	1211
Pore volumes									0	0.5	1.7	3.2	5.3	7.5	11.5	16.3	22.6	37.7	91.6	150.6	154.0	193.6	229.2	239.2
	Flow Rate Readings																							
Volume collected (mL)			87	127	127	128	120	122		130	128	128	126	127	127	127	127	124	115	102	99	93	81	64
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings				55				55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	1.5	29.35	29.35	29.35	29.35				29.4	29.5	29.5	29.6	29.6	29.7	29.9	30.1	30.5	32.3	34.1	34.2	35.2	36.9	37.4
Point 4 (cm)	8.5	8.5	29.25	29.15	29.2	29.2				29.2	29.2	29.3	29.4	29.4	29.4	29.5	29.6	29.9	31.1	32.5	32.7	33.6	34.6	35.1
Point 6 (cm)	16.5	16.5	28.9	28.75	28.8	28.8				28.8	28.8	28.8	28.8	28.9	28.8	28.9	29.0	29.1	29.8	30.5	30.7	31.2	31.7	32.0
Point 9 (cm)	23.5	23.5	28.45	28.25	28.25	28.3				28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.4	28.4	28.7	28.9	29.0	29.1	29.2	29.4
	25			4.233333	mL/s	28				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L	4.23E-06	Turb.		0	2.6	123	141	164	208	305	481	780	1100						
Calculations				1000	L/m^3																			
Q (m3/s)			2.9E-06	4.23E-06	4.23E-06	4.27E-06	0.000004	4.07E-06		4.33E-06	4.27E-06	4.27E-06	4.2E-06	4.23E-06	4.23E-06	4.23E-06	4.23E-06	4.13E-06	3.83E-06	3.4E-06	3.3E-06	3.1E-06	2.7E-06	2.13E-06
i (Point 1-4)			0.01	0.03	0.02	0.02	0.00	0.00		0.02	0.04	0.03	0.03	0.03	0.04	0.06	0.06	0.09	0.17	0.24	0.21	0.22	0.32	0.34
i (Point 1-9)			0.04	0.05	0.05	0.05	0.00	0.00		0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.08	0.09	0.16	0.24	0.24	0.28	0.35	0.36
i (Point 6-9)			0.06	0.07	0.08	0.07	0.00	0.00		0.07	0.07	0.07	0.07	0.08	0.07	0.09	0.09	0.10	0.15	0.23	0.24	0.30	0.36	0.37
i (Point 4-6)			0.04	0.05	0.05	0.05	0.00	0.00		0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.09	0.17	0.24	0.25	0.30	0.36	0.38
K (m/s)																								
(Point 1-4)			2.0E-02	1.4E-02	1.9E-02	1.9E-02	#DIV/0!	#DIV/0!		1.9E-02	1.2E-02	1.4E-02	1.4E-02	1.4E-02	9.5E-03	7.1E-03	6.3E-03	4.6E-03	2.2E-03	1.4E-03	1.5E-03	1.3E-03	8.1E-04	6.1E-04
(Point 1-9)			6.8E-03	8.2E-03	8.2E-03	8.6E-03	#DIV/0!	#DIV/0!		8.3E-03	7.5E-03	7.5E-03	7.1E-03	6.9E-03	6.4E-03	5.8E-03	5.3E-03	4.3E-03	2.3E-03	1.4E-03	1.3E-03	1.1E-03	7.5E-04	5.6E-04
(Point 6-9)			4.3E-03	5.7E-03	5.2E-03	5.8E-03	#DIV/0!	#DIV/0!		5.8E-03	5.8E-03	5.8E-03	5.7E-03	5.2E-03	5.7E-03	4.8E-03	4.8E-03	4.0E-03	2.5E-03	1.4E-03	1.3E-03	9.9E-04	7.3E-04	5.5E-04
(Point 4-6)			6.4E-03	8.2E-03	8.2E-03	8.2E-03	#DIV/0!	#DIV/0!		7.4E-03	7.3E-03	6.6E-03	5.9E-03	5.9E-03	5.4E-03	5.9E-03	5.0E-03	4.2E-03	2.2E-03	1.3E-03	1.3E-03	9.9E-04	7.2E-04	5.4E-04
% of Ko (1-4)		Ko =					1.9E-02		1.00	1.02	0.60	0.75	0.74	0.74	0.50	0.37	0.33	0.24	0.11	0.07	0.08	0.07	0.04	0.03
% of Ko (1-9)		Ko =					8.6E-03		1.00	0.97	0.88	0.88	0.83	0.80	0.74	0.67	0.61	0.50	0.26	0.16	0.16	0.13	0.09	0.07
% of Ko (6-9)		Ko =					5.8E-03		1.00	1.02	1.00	1.00	0.98	0.90	0.99	0.83	0.83	0.69	0.43	0.25	0.23	0.17	0.13	0.10
% of Ko (4-6)		Ko =					8.2E-03		1.00	0.90	0.89	0.80	0.72	0.72	0.66	0.72	0.61	0.52	0.27	0.16	0.15	0.12	0.09	0.07

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
S-1		1021.7	998.1	23.6	2.3%	3
S-2		1075.2	1050.1	25.1	2.3%	2
S-3		1483.2	1385.0	98.2	6.6%	1
		3580.10	3433.20	146.90	4.1%	
			Post-test total mass of fines	147	g	4.3E-02
			Mass of fines injected	1267	g	

Constant HeadTest min ml s

Test AN 2nd setup v = 0.000862 m/s ml s min 38000 1.06

Date 13-Sep-07 Water Properties (T= 20C) 40280

Sand Uniform sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 101.3 142.2 187.6 216.5 231.7 236.7 255.3 267.5

Clay in suspension 0.1% Batt. Till (1 g/L) 1 g/L

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	6.5	17	25	39	81.5	175	240	362	509	729	987	1162	1259	1292	1418	1503
Pore volumes								0	1.3	3.4	5.1	7.9	16.3	34.4	46.7	69.2	95.7	134.2	177.0	204.4	218.7	223.4	241.0	252.5
Volume collected (mL)		109.5	108	108.5	106.5	107.5	79.5		107	107.5	107	106	104	101.5	98.5	96.5	94.5	91	85	80.5	76	76	71.5	71.5
Time taken to collect (s)		30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0					55			55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	29.25	29.4	29.45	29.55	29.55			29.6	29.7	29.7	29.7	29.7	30.0	30.1	30.5	30.9	31.6	33.1	33.8	34.1	34.2	34.6	34.8
Point 4 (cm)	8.5	28.95	29.05	29.1	29.1	29.1			29.2	29.2	29.2	29.2	29.2	29.3	29.4	29.7	30.0	30.4	31.0	31.5	31.8	31.8	32.0	32.2
Point 6 (cm)	16.5	28.65	28.7	28.75	28.7	28.7			28.7	28.8	28.8	28.8	28.7	28.8	28.8	29.4	29.0	29.3	29.4	29.6	30.0	29.8	29.9	30.0
Point 9 (cm)	23.5	28.25	28.25	28.3	28.2	28.2			28.2	28.2	28.3	28.3	28.2	28.2	28.3	28.2	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
	25		3.6		3.6E-06	28			28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
			1000 mL/L				Turb.	0	30.0	39.0	40	38	28	36	38	60	124	212	227	303	338	309	310	406
Calculations			1000 L/m^3																					
Q (m3/s)		3.65E-06	3.6E-06	3.62E-06	3.55E-06	3.58E-06	2.65E-06		3.567E-06	3.583E-06	3.567E-06	3.533E-06	3.467E-06	3.383E-06	3.283E-06	3.217E-06	3.15E-06	3.033E-06	2.833E-06	2.683E-06	2.53E-06	2.53E-06	2.38E-06	2.38E-06
i (Point 1-4)		0.04	0.05	0.05	0.06	0.06	0.00		0.06	0.07	0.07	0.07	0.07	0.09	0.10	0.11	0.13	0.17	0.29	0.32	0.34	0.34	0.36	0.37
i (Point 1-9)		0.05	0.05	0.05	0.06	0.06	0.00		0.06	0.07	0.06	0.07	0.07	0.08	0.08	0.10	0.12	0.15	0.22	0.25	0.26	0.27	0.28	0.29
i (Point 6-9)		0.06	0.06	0.06	0.07	0.07	0.00		0.07	0.08	0.07	0.07	0.08	0.09	0.08	0.17	0.11	0.14	0.16	0.19	0.24	0.21	0.23	0.24
i (Point 4-6)		0.04	0.04	0.04	0.05	0.05	0.00		0.06	0.05	0.05	0.06	0.06	0.06	0.07	0.04	0.12	0.14	0.20	0.24	0.23	0.25	0.26	0.28
K (m/s)																								
(Point 1-4)		8.2E-03	6.9E-03	7.0E-03	5.3E-03	5.4E-03	#DIV/0!		5.3E-03	4.8E-03	4.8E-03	4.8E-03	4.7E-03	3.5E-03	3.2E-03	2.7E-03	2.4E-03	1.7E-03	9.3E-04	8.0E-04	7.3E-04	7.1E-04	6.3E-04	6.2E-04
(Point 1-9)		7.7E-03	6.6E-03	6.7E-03	5.6E-03	5.6E-03	#DIV/0!		5.4E-03	5.2E-03	5.4E-03	5.2E-03	4.9E-03	4.0E-03	3.8E-03	3.0E-03	2.6E-03	1.9E-03	1.3E-03	1.0E-03	9.3E-04	9.2E-04	8.1E-04	7.8E-04
(Point 6-9)		6.1E-03	5.4E-03	5.4E-03	4.8E-03	4.8E-03	#DIV/0!		4.8E-03	4.4E-03	4.8E-03	4.8E-03	4.2E-03	3.5E-03	4.0E-03	1.8E-03	2.8E-03	2.0E-03	1.7E-03	1.4E-03	1.0E-03	1.2E-03	1.0E-03	9.7E-04
(Point 4-6)		9.4E-03	7.9E-03	8.0E-03	6.8E-03	6.9E-03	#DIV/0!		6.1E-03	6.9E-03	6.9E-03	6.0E-03	5.9E-03	5.2E-03	4.2E-03	8.3E-03	2.6E-03	2.0E-03	1.4E-03	1.1E-03	1.1E-03	9.8E-04	8.7E-04	8.3E-04
% of Ko (1-4)	Ko =					5.4E-03		1.00	1.00	0.90	0.90	0.89	0.87	0.65	0.59	0.50	0.44	0.32	0.17	0.15	0.14	0.13	0.12	0.12
% of Ko (1-9)	Ko =					5.6E-03		1.00	0.96	0.93	0.96	0.92	0.87	0.71	0.67	0.53	0.46	0.34	0.22	0.19	0.16	0.16	0.14	0.14
% of Ko (6-9)	Ko =					4.8E-03		1.00	1.00	0.91	1.00	0.99	0.88	0.73			0.59	0.42	0.34	0.29	0.21	0.24	0.21	0.20
% of Ko (4-6)	Ko =					6.9E-03		1.00	0.88	1.00	1.00	0.88	0.86	0.76	0.61	1.20	0.37	0.29	0.20	0.16	0.16	0.14	0.13	0.12

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
AN-1	87.53	657.11	633.92	23.19	4.1%	3
AN-2	93.17	675.99	655.26	20.73	3.6%	
AN-3	94.22	616.89	594.05	22.84	4.4%	1
AN-4	90.66	688.05	659.93	28.12	4.7%	
AN-5	78.56	711.17	678.5	32.67	5.2%	
AN-6	102.06	758	706.92	51.08	7.8%	1
	5.5E+02	4.1E+03	3.9E+03	1.8E+02	5.0%	
			Post-test total mass of fines	179 g		4.5E-02
			Mass of fines injected	277 g		

277 g

272.6 277.0 L

1539	1569
257.3	261.5
72.5	73
30	30
15	15
55	55
34.9	35.1
32.3	32.4
30.0	30.2
28.4	28.4
28.0	28.0
328	524
2.42E-06	2.43E-06
0.38	0.38
0.30	0.30
0.24	0.26
0.28	0.28
6.1E-04	6.2E-04
7.8E-04	7.7E-04
9.9E-04	9.1E-04
8.3E-04	8.3E-04

Constant HeadTest

Date	May 16, 2007									Water Properties (T= 20C)												
Sand	Unimin			A (m2)	0.01039					γ (kN/m3)	9.7866	9.8E-04										
Clay in suspension	0.5%	Battleford Till fines		Water only																		
Time after beginning flow with suspension of fines (min)																						
	Elevation	Water	Water	Water	Water		0	3	13	33	67	109	166	223	243	266	291	319	341	362		
Pore volumes							0	0.6	2.6	6.6	13.5	21.9	33.6	45.5	49.6	54.4	59.6	65.3	69.7	73.9		
Flow Rate Readings																						
Volume collected (mL)		205	215	213	129	129		213	213	213	213	213	220	222	220	219	219	215	213	210		
Time taken to collect (s)		60	60	60	120	120		60	60	60	60	60	60	60	60	60	60	60	60	60		
Temperature of water (C)		15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15		
Manometer Readings																						
Point 1 (cm)	1.5	30.8	30.7	30.7				30.7	30.7	30.7	30.7	30.8	31.0	30.9	31.0	31.0	31.0	31.1	31.3	31.3		
Point 2 (cm)	3																					
Point 3 (cm)	4.5																					
Point 4 (cm)	8.5	30.6	30.5	30.5				30.5	30.5	30.5	30.5	30.5	30.6	30.5	30.6	30.6	30.6	30.6	30.7	30.7		
Point 5 (cm)	12.5																					
Point 6 (cm)	16.5	30.3	30.3	30.2				30.2	30.2	30.2	30.2	30.2	30.2	30.1	30.1	30.1	30.1	30.1	30.1	30.1		
Point 7 (cm)	20.5																					
Point 8 (cm)	22																					
Point 9 (cm)	23.5	29.7	29.6	29.6				29.6	29.6	29.6	29.6	29.6	29.6	29.5	29.5	29.4	29.4	29.4	29.4	29.4		
			3.583333	mL/s	3.58E-06																	
			1000	mL/L																		
Calculations			1000	L/m^3																		
Q (m3/s)		3.42E-06	3.58E-06	3.55E-06	1.08E-06	1.08E-06		0.00000355	0.00000355	0.00000355	0.00000355	0.00000355	3.6667E-06	0.0000037	3.6667E-06	0.00000365	0.00000365	3.5833E-06	0.00000355	0.0000035		
i (Point 1-3)		10.27	10.23	10.23	0.00	0.00		10.23	10.23	10.23	10.23	10.27	10.33	10.30	10.33	10.33	10.33	10.37	10.43	10.43		
i (Point 1-4)		0.03	0.03	0.03	0.00	0.00		0.03	0.03	0.03	0.03	0.04	0.06	0.06	0.06	0.06	0.06	0.07	0.09	0.09		
i (Point 1-9)		0.05	0.05	0.05	0.00	0.00		0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.07	0.07	0.07	0.08	0.09	0.09		
i (Point 6-9)		0.09	0.10	0.09	0.00	0.00		0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10		
i (Point 3-7)		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
i (Point 3-6)		-2.53	-2.53	-2.52	0.00	0.00		-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51		
i (Point 4-7)		2.55	2.54	2.54	0.00	0.00		2.54	2.54	2.54	2.54	2.54	2.55	2.54	2.55	2.55	2.55	2.55	2.56	2.56		
K (m/s)																						
(Point 1-3)		3.2E-05	3.4E-05	3.3E-05	#DIV/0!	#DIV/0!		3.3E-05	3.3E-05	3.3E-05	3.3E-05	3.3E-05	3.4E-05	3.5E-05	3.4E-05	3.4E-05	3.4E-05	3.3E-05	3.3E-05	3.2E-05		
(Point 1-4)		1.15E-02	1.21E-02	1.20E-02	#DIV/0!	#DIV/0!		1.2E-02	1.2E-02	1.2E-02	1.2E-02	8.0E-03	6.2E-03	6.2E-03	6.2E-03	6.1E-03	6.1E-03	4.8E-03	4.0E-03	3.9E-03		
(Point 1-9)		6.58E-03	6.90E-03	6.84E-03	#DIV/0!	#DIV/0!		6.8E-03	6.8E-03	6.8E-03	6.8E-03	6.3E-03	5.5E-03	5.6E-03	5.2E-03	4.8E-03	4.8E-03	4.5E-03	4.0E-03	3.9E-03		
(Point 6-9)		3.84E-03	3.45E-03	3.99E-03	#DIV/0!	#DIV/0!		4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.0E-03	4.1E-03	4.2E-03	4.1E-03	3.5E-03	3.5E-03	3.4E-03	3.4E-03	3.4E-03		
(Point 3-7)		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
(Point 3-6)		-1.3E-04	-1.4E-04	-1.4E-04	#DIV/0!	#DIV/0!		-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.4E-04	-1.3E-04		
(Point 4-7)		1.3E-04	1.4E-04	1.3E-04	#DIV/0!	#DIV/0!		1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.3E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04		
					1.2E-02		1.00	1.00	1.00	1.00	1.00	0.67	0.52	0.52	0.52	0.51	0.51	0.40	0.33	0.33		
% of Ko (1-9)	Ko =				6.8E-03		1.00	1.00	1.00	1.00	1.00	0.92	0.81	0.82	0.76	0.71	0.71	0.65	0.58	0.57		
					4.0E-03		1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.04	1.03	0.88	0.88	0.87	0.86	0.85		

Constant HeadTest min ml s

Test AK 1st setup ml s min

Date 11-Sep-07 Water Properties (T= 20C) Influent not well mixed

Sand Uniform sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04

Clay in suspension 0.1% Batt. Till (1 g/L)

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	4	14	38	83	129	172	561
Pore volumes								0	0.9	3.2	8.6	18.8	29.2	38.9	121.1
Volume collected (mL)		129.5	126.5	124.5	119.5	120.5	79.5		120	119.5	120.5	120	120	118	106
Time taken to collect (s)		30	30	30	30	30	30		30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15
Manometer Readings															
Point 1 (cm)	4.2	28.35	28.4	28.4	29.55	29.55			29.6	29.6	29.7	30.0	30.2	30.4	31.6
Point 2 (cm)	5.8														
Point 3 (cm)	7.2														
Point 4 (cm)	11.2	28.15	28.2	28.2	28.9	28.9			28.9	28.9	29.0	29.1	29.3	29.4	30.1
Point 5 (cm)	15.2														
Point 6 (cm)	19.2	27.85	27.8	27.8	28.2	28.2			28.2	28.2	28.2	28.3	28.3	28.4	28.4
Point 7 (cm)	23.2														
Point 8 (cm)	24.7														
Point 9 (cm)	26.2	27.35	27.3	27.25	27.55	27.5			27.5	27.5	27.5	27.5	27.5	27.5	27.3
			4.216667		4.22E-06										
			1000	mL/L			Turb.	0	13.0	21.0	25	30	36	40	51
Calculations			1000	L/m^3											
Q (m3/s)		4.32E-06	4.22E-06	4.15E-06	3.98E-06	4.02E-06	2.65E-06		0.000004	3.983E-06	4.017E-06	0.000004	0.000004	3.933E-06	3.533E-06
i (Point 1-3)		9.45	9.47	9.47	9.85	9.85	0.00		9.85	9.87	9.90	9.98	10.07	10.13	10.53
i (Point 1-4)		0.03	0.03	0.03	0.09	0.09	0.00		0.09	0.10	0.10	0.12	0.14	0.15	0.21
i (Point 1-9)		0.05	0.05	0.05	0.09	0.09	0.00		0.09	0.10	0.10	0.11	0.12	0.13	0.20
i (Point 6-9)		0.07	0.07	0.08	0.09	0.10	0.00		0.10	0.10	0.11	0.11	0.11	0.12	0.16
i (Point 3-6)		-2.32	-2.32	-2.32	-2.35	-2.35	0.00		-2.35	-2.35	-2.35	-2.35	-2.36	-2.36	-2.37
i (Point 4-7)		2.35	2.35	2.35	2.41	2.41	0.00		2.41	2.41	2.42	2.43	2.44	2.45	2.51
K (m/s)															
(Point 1-3)		4.4E-05	4.3E-05	4.2E-05	3.9E-05	3.9E-05	#DIV/0!		3.9E-05	3.9E-05	3.9E-05	3.9E-05	3.8E-05	3.7E-05	3.2E-05
(Point 1-4)		1.5E-02	1.4E-02	1.4E-02	4.1E-03	4.2E-03	#DIV/0!		4.1E-03	3.8E-03	3.9E-03	3.2E-03	2.8E-03	2.5E-03	1.6E-03
(Point 1-9)		9.1E-03	8.1E-03	7.6E-03	4.2E-03	4.2E-03	#DIV/0!		4.1E-03	4.0E-03	3.8E-03	3.5E-03	3.1E-03	2.9E-03	1.7E-03
(Point 6-9)		5.8E-03	5.7E-03	5.1E-03	4.1E-03	3.9E-03	#DIV/0!		3.9E-03	3.8E-03	3.6E-03	3.6E-03	3.4E-03	3.1E-03	2.1E-03
(Point 3-6)		-1.8E-04	-1.8E-04	-1.7E-04	-1.6E-04	-1.6E-04	#DIV/0!		-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.6E-04	-1.4E-04
(Point 4-7)		1.8E-04	1.7E-04	1.7E-04	1.6E-04	1.6E-04	#DIV/0!		1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.6E-04	1.5E-04	1.4E-04
% of Ko (1-3)	Ko =														
% of Ko (1-4)	Ko =					4.2E-03		1.00	1.00	0.92	0.93	0.76	0.68	0.61	0.38
% of Ko (1-9)	Ko =					4.2E-03		1.00	1.00	0.97	0.91	0.83	0.76	0.69	0.41
% of Ko (6-9)	Ko =					3.9E-03		1.00	1.00	0.99	0.93	0.93	0.87	0.81	0.54

Coarse Graded Sand with Kaolinite

Constant HeadTest					v	1.12E-06				min		ml	s								
		Test Y	1st setup		q	0.00042					ml	s	min			38000	1.06				1548 grams
Date		27-Jul-07			N_R	1.24					Water Properties (T= 20C)					40280					
Sand		Coarse gradation			A (m2)	0.01039					γ (kN/m3)	9.7866	μ (Ns/m2)	9.8E-04				201.1	261.1		310 litres
Clay in suspension		0.5%	(kaolinite)																		
	Time after beginning flow with suspension of fines (min)																				
		Elevation	Water	Water	Water	Water	Water	Water	0	3	7.5	15	45	183	244	327	544	803	1053	1258	
Pore volumes			0	1	2	3	4	5	0	1.0	2.4	4.8	14.3	57.5	76.4	101.9	167.7	244.9	318.0	376.9	
		Flow Rate Readings																			
Volume collected (mL)			127	127	132	131	116	118		131	131	131	130	127	127	125	124	121	119	117	
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	
	0					55				55	55	55	55	55	55	55	55	55	55	55	
Point 1 (cm)	1.5	1.5	29.1	28.85	28.85	28.75				28.8	28.9	28.9	29.1	29.7	29.9	30.1	30.5	30.8	31.1	31.35	
Point 4 (cm)	8.5	8.5	29			28.7				28.8	28.8	28.9	29.0	29.4	29.6	29.7	30.0	30.2	30.3	30.5	
Point 6 (cm)	16.5	16.5	28.5			28.3				28.3	28.3	28.3	28.4	28.5	28.5	28.5	28.5	28.3	28.3	28.35	
Point 9 (cm)	23.5	23.5	28.05	27.95	28	27.9				27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.8	27.6	27.5	27.5	
	25			4.233333	mL/s	28				28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	
				1000	mL/L	4.23E-06		Turb.	0	1100.0											
Calculations		0.2		1000	L/m^3																
Q (m3/s)			4.23E-06	4.23E-06	4.4E-06	4.37E-06	3.87E-06	3.93E-06		4.367E-06	4.367E-06	4.367E-06	4.333E-06	4.233E-06	4.233E-06	4.167E-06	4.133E-06	4.033E-06	3.967E-06	0.0000039	
i (Point 1-4)			0.01	4.12	4.12	0.01	0.00	0.00		0.01	0.01	0.01	0.01	0.04	0.04	0.06	0.07	0.09	0.11	0.12	
i (Point 1-9)			0.05	0.04	0.04	0.04	0.00	0.00		0.04	0.04	0.05	0.05	0.08	0.09	0.10	0.12	0.15	0.16	0.18	
i (Point 6-9)			0.06	-3.99	-4.00	0.06	0.00	0.00		0.06	0.06	0.06	0.06	0.09	0.09	0.09	0.09	0.11	0.11	0.12	
i (Point 4-6)			0.06	0.00	0.00	0.05	0.00	0.00		0.06	0.06	0.07	0.07	0.11	0.13	0.15	0.19	0.23	0.24	0.27	
K (m/s)																					
(Point 1-4)			2.9E-02	9.9E-05	1.0E-04	5.9E-02	#DIV/0!	#DIV/0!		5.9E-02	5.9E-02	5.9E-02	2.9E-02	1.1E-02	9.5E-03	7.0E-03	5.6E-03	4.2E-03	3.3E-03	3.1E-03	
(Point 1-9)			8.5E-03	1.0E-02	1.1E-02	1.1E-02	#DIV/0!	#DIV/0!	1.1E-02	1.0E-02	9.7E-03	9.2E-03	8.0E-03	5.1E-03	4.6E-03	4.0E-03	3.2E-03	2.6E-03	2.4E-03	2.1E-03	
(Point 6-9)			6.3E-03	-1.0E-04	-1.1E-04	7.4E-03	#DIV/0!	#DIV/0!		7.4E-03	7.4E-03	7.4E-03	6.5E-03	4.8E-03	4.8E-03	4.7E-03	4.3E-03	3.6E-03	3.3E-03	3.1E-03	
(Point 4-6)			6.5E-03	#DIV/0!	#DIV/0!	8.4E-03	#DIV/0!	#DIV/0!		7.5E-03	6.7E-03	6.1E-03	5.6E-03	3.6E-03	3.1E-03	2.7E-03	2.1E-03	1.7E-03	1.6E-03	1.4E-03	
									1.1E+00	1.0E+00	9.7E-01	9.2E-01	8.0E-01	5.1E-01	4.6E-01	4.0E-01	3.2E-01	2.6E-01	2.4E-01	2.1E-01	
% of Ko (1-4)		Ko =					5.9E-02		1.00	1.00	1.00	1.00	0.50	0.19	0.16	0.12	0.09	0.07	0.06	0.05	
% of Ko (1-9)		Ko =					1.1E-02		1.00	0.94	0.89	0.85	0.73	0.47	0.42	0.37	0.30	0.24	0.22	0.20	
% of Ko (6-9)		Ko =					7.4E-03		1.00	1.00	1.00	1.00	0.88	0.65	0.65	0.64	0.58	0.49	0.45	0.42	
% of Ko (4-6)		Ko =					8.4E-03		1.00	0.89	0.80	0.73	0.66	0.43	0.37	0.32	0.24	0.20	0.19	0.17	
		Sample	Tare	Pre-wash	Post-wash	Fines	% Fines					Tare	14.39	14.60		14.37	14.34	13.24	14.29	14.58	
Top of column (out)		Y-1	108.27	755.86	737.70	18.16	2.8%	3				Volume	9.80	9.80		9.80	10.00	9.70	9.80	9.70	
		Y-2	101.19	643.17	626.20	16.97	3.1%					Mass After	14.42	14.64		14.42	14.40	13.28	14.33	14.66	
		Y-3	86.70	687.14	666.92	20.22	3.4%	2				g solids	0.03	0.04		0.05	0.06	0.04	0.04	0.08	
		Y-4	78.56	767.63	741.98	25.65	3.7%					g clay	0.03	0.04		0.05	0.06	0.04	0.04	0.08	
		Y-5	94.56	696.80	677.55	19.25	3.2%					clay (g/L)	3.06	4.08		5.10	6.00	4.12	4.08	8.25	
Bottom of column (in)		Y-6	82.27	791.24	761.18	30.06	4.2%	1													
			5.5E+02	4.3E+03	4.2E+03	1.3E+02	3.4%										6				
					Post-test total mass of fines	130	g	3.1E-02													
					Mass of fines injected	1548	g														
						8.4%															

Constant HeadTest					v	1.17E-06				min		ml	s										
		Test U			q	0.000379					ml	s	min					38000	1.06			971	1034
Date		23-Jul-07			N_R	1.07					Water Properties (T= 20C)							40280					
Sand		Coarse gradation			A (m2)	0.01039					γ (N/m3)	9786.6	μ (Ns/m2)	9.8E-04							175.9	194.2	206.8
Clay in suspension		0.5%	(kaolinite)	5	g/L												*Test stopped and restarted - subtract 210 minutes						
	Time after beginning flow with suspension of fines (min)																						
		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	2	5	16	28	53	75	197	211	458	778	833	914	1029	1112
Pore volumes			0	1	2	3	4	5	0	0.6	1.4	4.4	7.7	14.4	20.1	51.5	55.0	114.5	186.6	198.0	214.2	236.5	251.9
		Flow Rate Readings																					
Volume collected (mL)			117	117	116	119	116	118		115	114	113	112	107	107	104	100	98	87	83	81	78	75
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings						55		55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	1.5	30.65	30.8	31.15	31.65	32.15	32.25		32.4	32.6	32.9	33.0	33.5	33.8	34.5	34.4	35.3	36.6	36.65	37.1	37.8	37.5
Point 4 (cm)	8.5	8.5	29.7	29.8	29.9	30.1	30.35	30.3		30.4	30.4	30.5	30.5	30.5	30.7	31.0	31.2	31.4	31.9	32	32.0	32.4	32.3
Point 6 (cm)	16.5	16.5	29.55	29.65	29.7	29.9	30.15	30.1		30.1	30.2	30.2	30.2	30.2	30.4	30.6	30.8	31.0	31.4	31.45	31.5	31.7	31.7
Point 9 (cm)	23.5	23.5	29.15	29.15	29.25	29.15	29.35	29.3		29.3	29.3	29.4	29.3	29.4	29.5	29.6	29.8	29.6	29.5	29.55	30.0	29.9	29.9
	25			3.9	mL/s	3.9E-06		28		28	28	28	28	28	28	28	28	28	28	28	28	28	28
				1000	mL/L			Turb.	0	159.0	828	1100											
Calculations				1000	L/m^3					6.7118644													
Q (m3/s)			3.9E-06	3.9E-06	3.87E-06	3.97E-06	3.87E-06	0.000004	0.000026	3.833E-06	0.0000038	3.767E-06	3.733E-06	3.567E-06	3.567E-06	3.467E-06	3.333E-06	3.267E-06	0.0000029	2.767E-06	2.7E-06	2.6E-06	2.5E-06
i (Point 1-4)			0.14	0.14	0.18	0.22	0.26	0.28		0.29	0.31	0.34	0.36	0.42	0.44	0.50	0.46	0.56	0.67	0.66	0.72	0.77	0.74
i (Point 1-9)			0.07	0.08	0.09	0.11	0.13	0.13	0.90	0.14	0.15	0.16	0.17	0.19	0.20	0.22	0.21	0.26	0.32	0.32	0.32	0.36	0.35
i (Point 6-9)			0.06	0.07	0.06	0.11	0.11	0.11		0.11	0.12	0.12	0.13	0.12	0.13	0.14	0.15	0.19	0.27	0.27	0.21	0.26	0.26
i (Point 4-6)			0.02	0.02	0.02	0.03	0.03	0.02		0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.04	0.06	0.06	0.07	0.07	0.09	0.07
						0.00038	V =	0.00038	0.00254	6.71													
					V/n =	0.00122	V*e =	0.00084	0.00564	6.71													
K (m/s)																							
(Point 1-4)			2.8E-03	2.6E-03	2.1E-03	1.7E-03	1.4E-03	1.4E-03		1.3E-03	1.2E-03	1.1E-03	9.9E-04	8.1E-04	7.8E-04	6.7E-04	7.0E-04	5.6E-04	4.2E-04	4.0E-04	3.6E-04	3.2E-04	3.2E-04
(Point 1-9)			5.5E-03	5.0E-03	4.3E-03	3.4E-03	2.9E-03	2.8E-03		2.6E-03	2.5E-03	2.3E-03	2.1E-03	1.8E-03	1.7E-03	1.5E-03	1.5E-03	1.2E-03	8.7E-04	8.3E-04	8.1E-04	6.9E-04	7.0E-04
(Point 6-9)			6.6E-03	5.3E-03	5.8E-03	3.6E-03	3.3E-03	3.3E-03		3.2E-03	3.0E-03	3.0E-03	2.8E-03	2.8E-03	2.7E-03	2.3E-03	2.1E-03	1.6E-03	1.0E-03	9.8E-04	1.2E-03	9.5E-04	9.4E-04
(Point 4-6)			2.0E-02	2.0E-02	1.5E-02	1.5E-02	1.5E-02	1.5E-02		1.2E-02	1.5E-02	9.7E-03	1.2E-02	9.2E-03	7.8E-03	6.7E-03	7.3E-03	5.6E-03	5.0E-03	3.9E-03	3.8E-03	2.9E-03	3.2E-03
% of Ko (1-4)		Ko =					1.4E-03		1.00	0.93	0.86	0.79	0.73	0.60	0.57	0.49	0.52	0.42	0.31	0.29	0.27	0.24	0.24
% of Ko (1-9)		Ko =					2.8E-03		1.00	0.93	0.88	0.81	0.76	0.65	0.61	0.53	0.54	0.43	0.31	0.29	0.29	0.25	0.25
% of Ko (6-9)		Ko =					3.3E-03		1.00	0.97	0.91	0.90	0.84	0.85	0.81	0.71	0.65	0.49	0.31	0.30	0.37	0.29	0.28
% of Ko (4-6)		Ko =					1.5E-02		1.00	0.78	0.97	0.64	0.76	0.60	0.52	0.44	0.48	0.37	0.33	0.26	0.25	0.19	0.21
		Sample	Tare	Pre-wash	Post-wash	Fines	% Fines																
		UA-1	95.11	652.84	634.60	18.24	3.3%	3									35	L	75.8				
		UA-2	81.83	614.77	596.38	18.39	3.5%										0.2	L/min					
		UA-3	92.56	784.90	767.91	16.99	2.5%	1									175						
		UA-4	86.24	822.25	791.78	30.47	4.1%										2.9166667						
		UA-5	84.19	817.19	783.12	34.07	4.6%																
		UA-6	94.18	687.24	658.76	28.48	4.8%	2															
			5.3E+02	4.4E+03	4.2E+03	1.5E+02	3.8%																
					Post-test total mass of fines	147	g	3.5E-02															
					Mass of fines injected	1230	g																
						11.9%																	

1131	1167	1230 grams
226.2	233.4	246 L

1242	1291	1379
275.5	284.3	299.7
74	73	71
30	30	30
15	15	15
55	55	55
37.8	38.2	38.3
32.7	32.7	32.9
32.0	32.0	32.2
30.2	30.1	30.5
28	28	28

2.47E-06	2.43E-06	2.37E-06
0.72	0.78	0.77
0.35	0.37	0.36
0.26	0.28	0.25
0.09	0.09	0.09

3.3E-04	3.0E-04	3.0E-04
6.9E-04	6.4E-04	6.4E-04
9.0E-04	8.4E-04	9.1E-04
2.7E-03	2.7E-03	2.6E-03

0.24	0.22	0.22
0.24	0.23	0.23
0.27	0.25	0.28
0.18	0.18	0.17

Constant HeadTest v 1.17E-06 min ml s 0.0530973

Test AJ (2nd setup but 1st col q 0.000363 ml s min 38000 1.06 662 grams

Date Sep 10, 2007 N_R 1.02 Water Properties (T= 20C) 40280

Sand Coarse gradation A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 129.7 132.5 L

Clay in suspension 0.3% (kaolinite) 2.5 g/L

Time after beginning flow with suspension of fines (min)

	Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	3.5	17.5	39	67	106	255	321	503	550	588	601
Pore volumes								0	1.0	4.8	10.7	18.4	29.0	69.2	86.8	135.3	147.9	158.0	161.3
Flow Rate Readings																			
Volume collected (mL)		118	117	114	113	113	116		113	113	113	112	112	109.5	109	110	110	106.5	107
Time taken to collect (s)		30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																			
Point 1 (cm)	1.5	29.1	29.15	29.3	29.35	29.5			29.6	29.7	29.7	29.9	30.1	30.8	30.9	31.1	31.2	31.25	31.3
Point 2 (cm)	3																		
Point 3 (cm)	4.5																		
Point 4 (cm)	8.5	28.7	28.65	28.8	28.8	28.85			28.9	28.9	28.9	29.0	29.1	29.4	29.5	29.5	29.6	29.6	29.6
Point 5 (cm)	12.5																		
Point 6 (cm)	16.5	28.7	28.55	28.55	28.55	28.55			28.6	28.6	28.6	28.6	28.7	28.8	28.9	28.9	29.0	29.0	29.1
Point 7 (cm)	20.5																		
Point 8 (cm)	22																		
Point 9 (cm)	23.5	28.4	28.15	28.1	28.1	28.05			28.1	28.1	28.0	28.1	28.1	28.1	28.1	28.1	28.2	28.2	28.2
			3.9	mL/s	3.9E-06														
			1000	mL/L			Turb.	0	538.0	1100									
Calculations			1000	L/m^3															
Q (m3/s)		3.93E-06	3.9E-06	3.8E-06	3.77E-06	0.000004		0.000051	3.767E-06	3.767E-06	3.767E-06	3.733E-06	3.733E-06	3.65E-06	3.633E-06	3.667E-06	3.667E-06	3.55E-06	3.567E-06
i (Point 1-3)		9.70	9.72	9.77	9.78	9.83			9.85	9.88	9.90	9.97	10.03	10.25	10.28	10.35	10.38	10.42	10.43
i (Point 1-4)		0.06	0.07	0.07	0.08	0.09			0.10	0.11	0.11	0.13	0.14	0.19	0.19	0.23	0.23	0.24	0.24
i (Point 1-9)		0.03	0.05	0.05	0.06	0.07		0.90	0.07	0.07	0.08	0.08	0.09	0.12	0.13	0.13	0.14	0.14	0.14
i (Point 6-9)		0.04	0.06	0.06	0.06	0.07			0.07	0.07	0.08	0.08	0.09	0.11	0.11	0.11	0.12	0.12	0.13
i (Point 4-6)		0.00	0.01	0.03	0.03	0.04			0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.07	0.07	0.08	0.07
i (Point 4-7)		2.39	2.39	2.40	2.40	2.40			2.40	2.40	2.41	2.42	2.43	2.45	2.46	2.45	2.46	2.47	2.47
					V =	0.000363	0.004952	13.66											
					V*e =	0.000164	0.002233	13.66											
K (m/s)																			
(Point 1-3)		3.9E-05	3.9E-05	3.7E-05	3.7E-05	3.7E-05	#DIV/0!		3.7E-05	3.7E-05	3.7E-05	3.6E-05	3.6E-05	3.4E-05	3.4E-05	3.4E-05	3.4E-05	3.3E-05	3.3E-05
(Point 1-4)		6.6E-03	5.3E-03	5.1E-03	4.6E-03	3.9E-03	#DIV/0!		3.6E-03	3.2E-03	3.2E-03	2.8E-03	2.5E-03	1.8E-03	1.8E-03	1.5E-03	1.5E-03	1.4E-03	1.4E-03
(Point 1-9)		1.2E-02	8.3E-03	6.7E-03	6.4E-03	5.5E-03	#DIV/0!		5.3E-03	5.0E-03	4.7E-03	4.3E-03	3.9E-03	2.9E-03	2.8E-03	2.6E-03	2.6E-03	2.4E-03	2.4E-03
(Point 6-9)		8.8E-03	6.6E-03	5.7E-03	5.6E-03	5.1E-03	#DIV/0!		5.1E-03	5.1E-03	4.6E-03	4.6E-03	4.2E-03	3.3E-03	3.1E-03	3.3E-03	2.9E-03	2.8E-03	2.7E-03
(Point 4-6)		#DIV/0!	3.0E-02	1.2E-02	1.2E-02	9.7E-03	#DIV/0!		9.7E-03	9.7E-03	8.3E-03	7.2E-03	6.4E-03	4.7E-03	4.7E-03	4.7E-03	5.1E-03	4.6E-03	5.0E-03
(Point 4-7)		1.6E-04	1.6E-04	1.5E-04	1.5E-04	1.5E-04	#DIV/0!		1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04	1.4E-04
% of Ko (1-4)	Ko =					3.9E-03		1.00	0.93	0.81	0.81	0.72	0.64	0.47	0.46	0.40	0.40	0.37	0.36
% of Ko (1-9)	Ko =					5.5E-03		1.00	0.97	0.91	0.85	0.78	0.70	0.52	0.51	0.48	0.47	0.44	0.44
% of Ko (4-9)	Ko =					5.1E-03		1.00	1.00	1.00	0.91	0.90	0.83	0.65	0.60	0.65	0.57	0.55	0.53
% of Ko (4-6)	Ko =					9.7E-03		1.00	1.00	1.00	0.86	0.74	0.66	0.48	0.48	0.49	0.53	0.47	0.52
	Sample	Tare	Pre-wash	Post-wash	Fines	% Fines		Tare	13.37		14.07		14.49	13.35		14.1		13.21	
	AJ-1	108.33	645.27	630.84	14.43	2.7%	2	Volume	19.6		19.65		19.3	19.9		19.95		19.55	
	AJ-2	92.58	620.55	611.52	9.03	1.7%		Mass After	13.95		14.95		15.26	13.97		15.22		13.82	
	AJ-3	84.35	726.22	711.67	14.55	2.3%	2	g solids	0.58		0.88		0.77	0.62		1.12		0.61	
	AJ-4	86.73	745.88	736.27	9.61	1.5%		g salt	0.57		0.57		0.56	0.58		0.58		0.57	
	AJ-5	86.05	713.22	700.89	12.33	2.0%		g clay	0.01		0.31		0.21	0.04		0.54		0.04	
	AJ-6	101.18	826.56	811.51	15.05	2.1%	1	clay (g/L)	0.37		15.56		10.68	1.94		26.92		1.98	
		5.6E+02	4.3E+03	4.2E+03	7.5E+01	2.0%													
		Post-test total mass of fines			75 g		1.8E-02												
		Mass of fines injected			662 g														

Constant HeadTest v 1.17E-06 http://www.lmnoeng. min ml s

Test V Setup #2 - 2nd Colum q 0.000347 ml s min 38000 1.06 241 grams

Date 23-Jul-07 N_R 0.98 Water Properties (T= 20C) 40280

Sand Coarse gradation A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 221.2 240.6 256.4

Clay in suspension 0.1% (kaolinite) 1 g/L

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	1	4	10	21	36	59	167	383	652	965	1027	1102	1207	1289
Pore volumes									0	0.3	1.0	2.6	5.5	9.4	15.5	43.5	97.9	164.1	238.8	252.9	269.4	293.1	312.2
		Flow Rate Readings																					
Volume collected (mL)			108	106	105	108	108	108		108	107	107	108	108	107	106	101	101	95	91	90	95	97
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings						55		55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	30.3	30.35	30.7	32.3	32.2	32.3		32.5	32.5	32.6	32.3	32.5	32.7	33.3	34.0	34.2	35.4	35.8	35.9	35.6	35.9
Point 4 (cm)	8.5	11.2	29.8	29.9	30.1	31.25	31.3	31.35		31.3	31.3	31.4	31.2	31.3	31.5	31.8	32.5	32.7	33.7	34.0	34.0	33.7	34.3
Point 6 (cm)	16.5	19.2	28.8	28.9	28.8	29.1	28.9	29		28.9	28.9	28.9	29.0	29.0	29.0	28.9	28.7	29.2	29.4	29.5	29.3	29.2	29.5
Point 9 (cm)	23.5	26.2	28.5	28.4	28.85	28.4	28.3	28.3		28.2	28.2	28.1	28.1	28.1	28.1	28.1	28.0	28.1	28.0	27.9	27.9	27.9	27.9
	25			3.533333	mL/s	3.53E-06		28		28	28	28	28	28	28	28	28	28	28	28	28	28	28
				1000	mL/L			Turb.	0	16.0	101	178	327	401	534	877	1100						
Calculations				1000	L/m^3																		
Q (m3/s)			3.6E-06	3.53E-06	3.5E-06	3.6E-06	3.6E-06	3.6E-06		3.6E-06	3.57E-06	3.57E-06	3.6E-06	3.6E-06	3.57E-06	3.53E-06	3.37E-06	3.37E-06	3.17E-06	3.03E-06	0.000003	3.17E-06	3.23E-06
i (Point 1-4)			0.07	0.06	0.09	0.15	0.13	0.14		0.17	0.17	0.17	0.16	0.17	0.18	0.22	0.21	0.21	0.24	0.26	0.27	0.26	0.24
i (Point 1-9)			0.08	0.09	0.08	0.18	0.18	0.18		0.20	0.20	0.20	0.19	0.20	0.21	0.24	0.27	0.28	0.33	0.36	0.36	0.35	0.37
i (Point 6-9)			0.04	0.07	-0.01	0.10	0.09	0.10		0.11	0.11	0.11	0.12	0.13	0.13	0.11	0.10	0.16	0.20	0.22	0.19	0.19	0.23
i (Point 4-6)			0.13	0.13	0.16	0.27	0.30	0.29		0.30	0.30	0.31	0.28	0.28	0.31	0.36	0.48	0.44	0.54	0.56	0.59	0.56	0.60
K (m/s)																							
(Point 1-4)			4.9E-03	5.3E-03	3.9E-03	2.3E-03	2.7E-03	2.6E-03		2.0E-03	2.0E-03	2.0E-03	2.2E-03	2.0E-03	1.9E-03	1.5E-03	1.6E-03	1.6E-03	1.3E-03	1.1E-03	1.1E-03	1.2E-03	1.3E-03
(Point 1-9)			4.2E-03	3.8E-03	4.0E-03	2.0E-03	2.0E-03	1.9E-03		1.8E-03	1.7E-03	1.7E-03	1.8E-03	1.8E-03	1.6E-03	1.4E-03	1.2E-03	1.2E-03	9.1E-04	8.2E-04	7.9E-04	8.7E-04	8.5E-04
(Point 6-9)			8.1E-03	4.8E-03	-4.7E-02	3.5E-03	4.0E-03	3.5E-03		3.2E-03	3.2E-03	3.2E-03	2.9E-03	2.7E-03	2.7E-03	3.0E-03	3.2E-03	2.1E-03	1.5E-03	1.3E-03	1.5E-03	1.6E-03	1.4E-03
(Point 4-6)			2.8E-03	2.7E-03	2.1E-03	1.3E-03	1.2E-03	1.2E-03		1.2E-03	1.1E-03	1.1E-03	1.3E-03	1.2E-03	1.1E-03	9.4E-04	6.8E-04	7.3E-04	5.7E-04	5.2E-04	4.9E-04	5.4E-04	5.2E-04
% of Ko (1-4)		Ko =					2.6E-03		1.00	0.79	0.78	0.78	0.86	0.79	0.75	0.60	0.61	0.61	0.51	0.44	0.42	0.45	0.52
% of Ko (1-9)		Ko =					1.9E-03		1.00	0.92	0.91	0.89	0.96	0.92	0.86	0.75	0.63	0.61	0.48	0.43	0.42	0.46	0.45
% of Ko (6-9)		Ko =					3.5E-03		1.00	0.93	0.92	0.92	0.82	0.78	0.77	0.86	0.94	0.60	0.44	0.38	0.43	0.46	0.39
% of Ko (4-6)		Ko =					1.2E-03		1.00	0.98	0.97	0.93	1.07	1.04	0.95	0.80	0.58	0.62	0.48	0.44	0.41	0.46	0.44

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
V-1	94.55	701.83	686.84	14.99	2.5%	2
V-2	82.27	664.43	646.78	17.65	3.0%	
V-3	108.28	771.77	749.25	22.52	3.4%	1
V-4	86.71	716.65	699.44	17.21	2.7%	
V-5	101.19	736.75	717.18	19.57	3.1%	
V-6	91.31	766.61	744.94	21.67	3.2%	2
	5.6E+02	4.4E+03	4.2E+03	1.1E+02	3.0%	
	Post-test total mass of fines			114 g		2.7E-02
	Mass of fines injected			310 g		
				36.7%		

35 L 75.8

0.188 L/min

186.1702

3.102837

310 grams

284.3 292.3 310 L

1435	1478	1572
346.2	356.0	377.5
94	94	93
30	30	30
15	15	15
55	55	55
36.6	36.0	36.4
34.9	34.3	34.7
29.3	29.3	29.2
27.9	28.0	27.9
28	28	28

3.13E-06	3.13E-06	3.1E-06
0.24	0.24	0.24
0.39	0.37	0.39
0.19	0.19	0.19
0.70	0.63	0.69

1.2E-03	1.2E-03	1.2E-03
7.7E-04	8.2E-04	7.7E-04
1.6E-03	1.6E-03	1.6E-03
4.3E-04	4.8E-04	4.3E-04

0.49	0.49	0.48
0.40	0.43	0.41
0.45	0.45	0.46
0.37	0.41	0.37

Constant HeadTest

		v	1.12E-06	min	ml	s					
Test AD	(2nd setup but 1st col	q	0.000369		ml	s	min	38000	1.06		1398 grams
Date	22-Aug-07	N_R	1.08		Water Properties (T= 20C)			40280			
Sand	Coarse gradation	A (m2)	0.01039		γ (kN/m3)	9.7866	μ (Ns/m2) 9.8E-04		242.7	260.1	279.5 L
Clay in suspension	0.5% (kaolinite)			Salt water							

Time after beginning flow with suspension of fines (min)

	Elevation	Water	Water	Water	Water	Water	Water	0	3	19	46	70	158	283	538	752	1047	1158	1250	1352
Pore volumes								0	0.8	5.3	12.6	19.2	42.9	76.2	143.3	198.0	269.9	295.6	316.7	340.5
Flow Rate Readings																				
Volume collected (mL)		115	115	116	115	116	116		115	112	112	112	109	110	106	104	96	94	95	96
Time taken to collect (s)		30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)		15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15
Manometer Readings																				
Point 1 (cm)	1.5	29.55	29.55	29.45	29.35	29.3	29.25		29.9	30.3	30.6	30.8	31.4	32.1	33.2	34.4	36.0	36	36.1	34.8
Point 2 (cm)	3																			
Point 3 (cm)	4.5																			
Point 4 (cm)	8.5	29	29	28.9	28.75	28.75	28.75		29.2	29.5	29.7	29.8	30.0	30.2	30.5	30.7	31.0	30.85	30.8	30.4
Point 5 (cm)	12.5																			
Point 6 (cm)	16.5	28.8	28.8	28.65	28.55	28.5	28.5		28.7	29.0	29.2	29.3	29.5	29.6	29.7	29.8	29.9	29.85	29.9	29.5
Point 7 (cm)	20.5																			
Point 8 (cm)	22																			
Point 9 (cm)	23.5	28.55	28.55	28.4	28.3	28.2	28.2		28.3	28.7	28.9	29.0	29.2	29.2	29.2	29.2	29.4	29.3	29.2	29.0

3.833333 mL/s 3.83E-06

1000 mL/L Turb. 0 913.0 1100

1000 L/m^3

Calculations																				
Q (m3/s)		3.83E-06	3.83E-06	3.87E-06	3.83E-06	3.87E-06	3.87E-06		3.83E-06	3.73E-06	3.73E-06	3.73E-06	3.63E-06	3.67E-06	3.53E-06	3.47E-06	3.2E-06	3.13E-06	3.17E-06	3.2E-06
i (Point 1-3)		9.85	9.85	9.82	9.78	9.77	9.75		9.95	10.08	10.18	10.25	10.45	10.68	11.07	11.45	12.00	12.00	12.03	11.58
i (Point 1-4)		0.08	0.08	0.08	0.09	0.08	0.07		0.10	0.11	0.13	0.14	0.19	0.26	0.39	0.53	0.72	0.74	0.76	0.62
i (Point 1-9)		0.05	0.05	0.05	0.05	0.05	0.05		0.07	0.07	0.08	0.08	0.10	0.13	0.18	0.23	0.30	0.30	0.31	0.26
i (Point 6-9)		0.04	0.04	0.04	0.04	0.04	0.04		0.06	0.04	0.04	0.04	0.05	0.06	0.07	0.08	0.07	0.08	0.09	0.07
i (Point 4-6)		0.02	0.02	0.03	0.02	0.03	0.03		0.06	0.06	0.06	0.06	0.06	0.07	0.10	0.11	0.13	0.13	0.11	0.11
i (Point 4-7)		2.42	2.42	2.41	2.40	2.40	2.40		2.43	2.46	2.47	2.48	2.50	2.52	2.54	2.55	2.58	2.57	2.56	2.53

K (m/s)																				
(Point 1-3)		3.7E-05	3.7E-05	3.8E-05	3.8E-05	3.8E-05	3.8E-05		3.7E-05	3.6E-05	3.5E-05	3.5E-05	3.3E-05	3.3E-05	3.1E-05	2.9E-05	2.6E-05	2.5E-05	2.5E-05	2.7E-05
(Point 1-4)		4.7E-03	4.7E-03	4.7E-03	4.3E-03	4.7E-03	5.2E-03		3.7E-03	3.4E-03	2.8E-03	2.5E-03	1.8E-03	1.3E-03	8.8E-04	6.3E-04	4.3E-04	4.1E-04	4.0E-04	5.0E-04
(Point 1-9)		8.1E-03	8.1E-03	7.8E-03	7.7E-03	7.4E-03	7.8E-03		5.1E-03	5.1E-03	4.8E-03	4.4E-03	3.5E-03	2.7E-03	1.9E-03	1.4E-03	1.0E-03	9.9E-04	9.7E-04	1.2E-03
(Point 6-9)		1.0E-02	1.0E-02	1.0E-02	1.0E-02	8.7E-03	8.7E-03		5.7E-03	8.4E-03	8.4E-03	8.4E-03	7.0E-03	6.2E-03	4.8E-03	4.2E-03	4.3E-03	3.8E-03	3.3E-03	4.3E-03
(Point 4-6)		1.5E-02	1.5E-02	1.2E-02	1.5E-02	1.2E-02	1.2E-02		6.6E-03	5.8E-03	6.4E-03	5.8E-03	5.6E-03	4.7E-03	3.4E-03	3.0E-03	2.3E-03	2.4E-03	2.7E-03	2.7E-03
(Point 4-7)		1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.6E-04	1.6E-04		1.5E-04	1.5E-04	1.5E-04	1.4E-04	1.4E-04	1.4E-04	1.3E-04	1.3E-04	1.2E-04	1.2E-04	1.2E-04	1.2E-04

% of Ko (1-4)	Ko =	4.7E-03	1.00	0.78	0.71	0.59	0.53	0.38	0.28	0.19	0.13	0.09	0.09	0.08	0.10
% of Ko (1-9)	Ko =	7.4E-03	1.00	0.68	0.69	0.64	0.59	0.47	0.37	0.25	0.19	0.14	0.13	0.13	0.16
% of Ko (6-9)	Ko =	8.7E-03	1.00	0.66	0.97	0.97	0.97	0.81	0.71	0.55	0.49	0.50	0.44	0.38	0.50
% of Ko (4-6)	Ko =	1.2E-02	1.00	0.55	0.48	0.54	0.48	0.47	0.40	0.29	0.25	0.20	0.20	0.23	0.23

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines	
AD-1	91.30	796.05	770.08	25.97	3.7%	3
AD-2	91.50	684.65	662.72	21.93	3.7%	
AD-3	90.89	651.63	629.85	21.78	3.9%	2
AD-4	86.07	656.48	632.34	24.14	4.2%	
AD-5	94.60	673.26	646.54	26.72	4.6%	
AD-6	87.01	866.33	828.62	37.71	4.8%	1

Tare	13.26	13.54	14.58
Volume	9.80	9.9	9.6
Mass After	13.57	13.87	14.88
g solids	0.31	0.33	0.30
g salt	0.29	0.29	0.28
g clay	0.02	0.04	0.02
clay (g/L)	2.41	4.11	2.03

Post-test total mass of fines 158 g

Mass of fines injected 1398 g

Coarse Graded Sand with Battleford Till fines

Constant HeadTest			q =	3.4E-04		min		ml	s			
	Test AP	2nd setup	v =	8.6E-04 m/s			ml	s	min			543 g
Date	04-Oct-07			8.6E-04	??		Water Properties (T= 20C)					
Sand	Coarse graded sand		A (m2)	1.0E-02			γ (kN/m3)	9.7866	μ (Ns/m2)	9.8E-04		108.6 L
Clay in suspension	0.5% Batt. Till	(5 g/L)										

Time after beginning flow with suspension of fines (min)

		Elevation	Water	Water	Water	Water	Water	Water	0	4.5	18	34	63	92	253	425	543
Pore volumes									0	0.9	3.6	6.9	12.7	18.5	50.5	82.5	102.5
Volume collected (mL)			106.5	107.5	107	106.5	107	79.5		107	107	106.5	106	105.5	105	92.5	87
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15
	0	ometer Readings					55			55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	1.5	30.25	30.15	30.15	30.2	30.2			30.2	30.3	30.3	30.4	30.5	31.2	32.1	33.0
Point 4 (cm)	8.5	8.5	29.3	29.25	29.25	29.25	29.25			29.3	29.3	29.3	29.4	29.4	29.9	30.4	31.1
Point 6 (cm)	16.5	16.5	29.2	29.1	29.05	29.05	29.05			29.1	29.1	29.1	29.1	29.1	29.4	29.7	30.1
Point 9 (cm)	23.5	23.5	29	28.85	28.8	28.8	28.8			28.8	28.8	28.8	28.8	28.8	28.9	28.9	29.1
	25			3.583333		3.58E-06	28			28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L			Turb.	0	611	857	1100					
Calculations				1000	L/m^3												
Q (m3/s)			3.55E-06	3.58E-06	3.57E-06	3.55E-06	3.57E-06	2.65E-06		3.57E-06	3.57E-06	3.55E-06	3.53E-06	3.52E-06	3.5E-06	3.08E-06	2.9E-06
i (Point 1-4)			0.14	0.13	0.13	0.14	0.14	0.00		0.13	0.14	0.14	0.14	0.15	0.19	0.24	0.27
i (Point 1-9)			0.06	0.06	0.06	0.06	0.06	0.00		0.06	0.07	0.07	0.07	0.07	0.11	0.15	0.18
i (Point 6-9)			0.03	0.04	0.04	0.04	0.04	0.00		0.04	0.04	0.04	0.04	0.04	0.08	0.11	0.15
i (Point 4-6)			0.01	0.02	0.02	0.02	0.02	0.00		0.03	0.03	0.03	0.04	0.04	0.06	0.09	0.12
K (m/s)																	
(Point 1-4)			3E-03	3E-03	3E-03	3E-03	3E-03	#DIV/0!		3E-03	3E-03	3E-03	3E-03	2E-03	2E-03	1E-03	1E-03
(Point 1-9)			6E-03	6E-03	6E-03	5E-03	5E-03	#DIV/0!		5E-03	5E-03	5E-03	5E-03	5E-03	3E-03	2E-03	2E-03
(Point 6-9)			1E-02	1E-02	1E-02	1E-02	1E-02	#DIV/0!		1E-02	1E-02	8E-03	8E-03	8E-03	4E-03	3E-03	2E-03
(Point 4-6)			3E-02	2E-02	1E-02	1E-02	1E-02	#DIV/0!		1E-02	1E-02	1E-02	9E-03	9E-03	5E-03	3E-03	2E-03

% of Ko (1-4)	Ko =	2.5E-03	1.00	1.06	1.00	1.00	0.99	0.89	0.72	0.48	0.41
% of Ko (1-9)	Ko =	5.4E-03	1.00	1.00	0.97	0.93	0.89	0.84	0.58	0.37	0.29
% of Ko (6-9)	Ko =	9.6E-03	1.00	1.00	1.00	0.83	0.83	0.82	0.45	0.27	0.19
% of Ko (1-3)	Ko =	1.4E-02	1.00	0.80	0.80	0.80	0.66	0.66	0.39	0.23	0.17

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines							
							Tare	14.24	14.60	14.52	14.32	14.15
AP-1	107.94	798.37	784.33	14.04	2.0%	1	Volume	19.55	19.25	19.35	18.75	19.60
AP-2	83.48	635.64	616.58	19.06	3.5%		Mass After	14.26	14.64	14.60	14.39	14.23
AP-3	91.81	754.79	742.13	12.66	1.9%	1	g solids	0.02	0.04	0.08	0.07	0.08
AP-4	78.28	661.65	649.39	12.26	2.1%		g salt	0.00	0.00	0.00	0.00	0.00
AP-5	87.02	739.16	716.45	22.71	3.5%		g clay	0.02	0.04	0.08	0.07	0.08
AP-6	87.01	859.02	811.35	47.67	6.2%	3	clay (g/L)	1.02	2.08	4.13	3.73	4.08

Post-test total mass of fines	128 g
Mass of fines injected	543 g
	23.6%

Constant HeadTest v 1.17E-06 min ml s

Test AI (1st setup but 2nd col q 0.000408 ml s min 780 grams

Date Sep 10, 2007 N_R 1.15 Water Properties (T= 20C)

Sand Coarse graded sand A (m2) 0.01039 γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04 152.4 156.0 L

Clay in suspension 0.5% Batt. Till 5 g/L

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	5	15	45	68	136	287	354	555	620	635
Pore volumes									0	1.5	4.6	13.8	20.8	41.2	86.0	106.1	166.3	185.6	190.0
Volume collected (mL)			123	128	127	127	127	79.5		126	126	125	125	121	123	123	123	121	120.5
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15
	0	meter Readings					55			55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	28.25	28	28.3	28.35	28.35			28.4	28.5	28.6	28.9	29.1	29.4	29.8	30.1	30.2	30.4
Point 4 (cm)	8.5	11.2	28.2	27.85	28.1	28.2	28.2			28.2	28.3	28.4	28.5	28.6	28.9	29.2	29.4	29.5	29.6
Point 6 (cm)	16.5	19.2	28.2	27.85	28	28.05	28.05			28.1	28.1	28.2	28.3	28.4	28.5	28.8	28.7	28.8	28.9
Point 9 (cm)	23.5	26.2	27.8	27.35	27.35	27.35	27.3			27.3	27.3	27.3	27.3	27.3	27.2	27.4	27.3	27.3	27.4
	25			4.266667		4.27E-06	28			28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L			Turb.	0	389.0	695.0	869	1100						
Calculations				1000	L/m^3														
Q (m3/s)			4.1E-06	4.27E-06	4.23E-06	4.23E-06	4.23E-06	2.65E-06		4.2E-06	4.2E-06	4.17E-06	4.17E-06	4.03E-06	4.1E-06	4.1E-06	4.1E-06	4.03E-06	4.02E-06
i (Point 1-4)			0.01	0.02	0.03	0.02	0.02	0.00		0.03	0.04	0.04	0.05	0.06	0.07	0.09	0.11	0.10	0.11
i (Point 1-9)			0.02	0.03	0.04	0.05	0.05	0.00		0.05	0.05	0.06	0.07	0.08	0.10	0.11	0.13	0.13	0.14
i (Point 6-9)			0.06	0.07	0.09	0.10	0.11	0.00		0.11	0.11	0.14	0.15	0.16	0.19	0.21	0.21	0.22	0.22
i (Point 4-6)			0.00	0.00	0.01	0.02	0.02	0.00		0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.08	0.08	0.09
K (m/s)																			
(Point 1-4)			5.5E-02	1.9E-02	1.4E-02	1.9E-02	1.9E-02	#DIV/0!		1.4E-02	1.1E-02	1.1E-02	8.0E-03	6.0E-03	5.5E-03	4.3E-03	3.7E-03	3.9E-03	3.6E-03
(Point 1-9)			1.9E-02	1.4E-02	9.4E-03	9.0E-03	8.5E-03	#DIV/0!		8.1E-03	7.4E-03	6.5E-03	5.5E-03	4.7E-03	4.0E-03	3.5E-03	3.0E-03	2.9E-03	2.8E-03
(Point 6-9)			6.9E-03	5.8E-03	4.4E-03	4.1E-03	3.8E-03	#DIV/0!		3.8E-03	3.5E-03	3.0E-03	2.7E-03	2.5E-03	2.1E-03	1.9E-03	1.9E-03	1.8E-03	1.7E-03
(Point 4-6)			#DIV/0!	#DIV/0!	3.3E-02	2.2E-02	2.2E-02	#DIV/0!		2.2E-02	2.2E-02	2.1E-02	1.6E-02	1.2E-02	9.0E-03	9.0E-03	4.9E-03	4.8E-03	4.4E-03
% of Ko (1-4)		Ko =					1.9E-02		1.00	0.74	0.60	0.59	0.42	0.32	0.29	0.22	0.19	0.20	0.19
% of Ko (1-9)		Ko =					8.5E-03		1.00	0.95	0.87	0.77	0.65	0.56	0.47	0.42	0.36	0.34	0.33
% of Ko (6-9)		Ko =					3.8E-03		1.00	0.99	0.93	0.78	0.70	0.65	0.56	0.50	0.50	0.46	0.46
% of Ko (1-3)		Ko =					2.2E-02		1.00	0.99	0.99	0.98	0.74	0.57	0.42	0.42	0.22	0.22	0.20

								Z2	16A				
Sample	Tare	Pre-wash	Post-wash	Fines	% Fines		Tare	14.31	14.10	13.70	14.64	14.58	14.36
A1-1	95.79	713.06	688.97	24.09	3.9%	3	Volume	19.30	19.45	19.15	19.15	19.25	19.60
A1-2	108.3	722.78	705.38	17.40	2.8%		Mass After	14.98	14.99	14.29	15.22	15.57	15.03
A1-3	89.78	630.86	615.03	15.83	2.9%	1	g solids	0.67	0.89	0.59	0.58	0.99	0.67
A1-4	86.33	784.59	764.5	20.09	2.9%		g salt	0.56	0.57	0.56	0.56	0.56	0.57
A1-5	96.96	680.89	665.88	15.01	2.6%		g clay	0.11	0.32	0.03	0.02	0.43	0.10
A1-6	81.86	726.39	716.73	9.66	1.5%	1	clay (g/L)	5.50	16.54	1.59	1.07	22.21	4.96
	5.6E+02	4.3E+03	4.2E+03	1.0E+02	2.8%								

Post-test total mass of fines 102 g 2.5E-02

Mass of fines injected 780 g

13.1%

48 L 75.8

Constant HeadTest

	Test AM	1st setup	v	1.17E-06	min		ml	s	
Date	Sep 13, 2007		N_R	1.07		ml	s	min	38000
Sand	Coarse graded sand		A (m2)	0.01039		Water Properties (T= 20C)			40280
Clay in suspension	0.1%	Batt. Till	1 g/L						

q = 0.00038

γ (kN/m3) 9.7866 μ (Ns/m2) 9.8E-04   35.0   42.2   47.1   55.3   60.4   84.0

Time after beginning flow with suspension of fines (min)

		Elevation	Brine	Brine	Brine	Brine	Brine	Brine	0	18.5	26	40.5	58.5	78.5	93	108.5	127.5	145	175	195	229	250	347
Pore volumes									0	5.5	7.7	11.9	17.1	22.9	27.2	31.8	37.5	42.6	51.4	57.3	67.4	73.6	102.3
Volume collected (mL)			123	119.5	120	120	119	118.5		121	120	119	119	121	121	122.5	122	121	119.5	121.5	122	120	123
Time taken to collect (s)			30	30	30	30	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	30
Temperature of water (C)			15	15	15	15	15	15		15	15	15	15	15	15	15	15	15	15	15	15	15	15
	0	ometer Readings						55		55	55	55	55	55	55	55	55	55	55	55	55	55	55
Point 1 (cm)	1.5	4.2	28.75	29.8	29.85	29.7	29.8	29.85		30.0	29.9	30.1	30.2	29.8	29.8	29.5	29.7	29.6	29.8	29.8	29.8	29.9	29.5
Point 4 (cm)	8.5	11.2	28.55	29.25	29.15	29	29.1	29.1		29.1	29.0	29.0	29.1	28.8	28.9	28.7	28.8	28.7	29.0	28.8	28.7	28.8	28.6
Point 6 (cm)	16.5	19.2	28.4	29	28.9	28.7	28.8	28.8		28.8	28.7	28.7	28.8	28.6	28.7	28.5	28.6	28.5	28.7	28.6	28.4	28.5	28.4
Point 9 (cm)	23.5	26.2	27.8	28.15	28.1	27.75	27.9	27.85		27.9	27.8	27.7	27.8	27.6	27.7	27.4	27.5	27.5	27.6	27.7	27.6	27.5	27.4
	25			3.983333		3.98E-06		28		28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0
				1000	mL/L			Turb.	0	100.0	114	128	132	167	164	182	203	221	211	197	188	223	254
Calculations				1000	L/m^3																		
Q (m3/s)			4.1E-06	3.98E-06	0.000004	0.000004	3.97E-06	3.95E-06		4E-06	4E-06	4E-06	4E-06	4E-06	4E-06	4.08E-06	4.07E-06	4.03E-06	3.98E-06	4.05E-06	4.07E-06	0.000004	4.1E-06
i (Point 1-4)			0.03	0.08	0.10	0.10	0.10	0.11		0.13	0.14	0.16	0.16	0.14	0.13	0.12	0.12	0.12	0.12	0.14	0.15	0.16	0.13
i (Point 1-9)			0.04	0.08	0.08	0.09	0.09	0.09		0.10	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10
i (Point 6-9)			0.09	0.12	0.11	0.14	0.13	0.14		0.14	0.13	0.14	0.14	0.14	0.14	0.16	0.16	0.15	0.16	0.12	0.11	0.14	0.14
i (Point 4-6)			0.02	0.03	0.03	0.04	0.04	0.04		0.04	0.04	0.04	0.04	0.02	0.03	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.03
K (m/s)																							
(Point 1-4)			1E-02	5E-03	4E-03	4E-03	4E-03	4E-03		3E-03	3E-03	2E-03	2E-03	3E-03	3E-03	3E-03	3E-03	3E-03	3E-03	3E-03	3E-03	2E-03	3E-03
(Point 1-9)			9E-03	5E-03	5E-03	4E-03	4E-03	4E-03		4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03	4E-03
(Point 6-9)			5E-03	3E-03	3E-03	3E-03	3E-03	3E-03		3E-03	3E-03	3E-03	3E-03	3E-03	3E-03	3E-03	2E-03	3E-03	2E-03	3E-03	3E-03	3E-03	3E-03
(Point 4-6)			2E-02	1E-02	1E-02	1E-02	1E-02	1E-02		1E-02	1E-02	1E-02	1E-02	2E-02	2E-02	2E-02	2E-02	2E-02	1E-02	1E-02	9E-03	9E-03	1E-02
% of Ko (1-4)		Ko =					3.5E-03		1.00	0.85	0.80	0.68	0.68	0.77	0.85	0.91	0.91	0.90	0.89	0.77	0.74	0.69	0.86
% of Ko (1-9)		Ko =					4.2E-03		1.00	0.95	0.94	0.85	0.84	0.93	0.97	0.96	0.96	0.97	0.90	0.98	0.94	0.84	0.97
% of Ko (6-9)		Ko =					2.8E-03		1.00	1.02	1.07	1.00	0.95	0.97	0.97	0.89	0.89	0.92	0.83	1.15	1.22	1.01	0.99
% of Ko (4-6)		Ko =					1.0E-02		1.00	1.02	1.01	1.00	1.00	1.53	1.53	1.55	1.54	1.53	1.21	1.23	0.88	0.87	1.25

Sample	Tare	Pre-wash	Post-wash	Fines	% Fines		Tare
AM-1	81.18	635.42	619.39	16.03	2.9%	2	Volume
AM-2	85.93	666.22	650.48	15.74	2.7%		Mass After
AM-3	89.91	719.31	709.11	10.20	1.6%	3	g solids
AM-4	94.56	774.29	764.64	9.65	1.4%		g salt
AM-5	88.43	787.28	774.63	12.65	1.8%		g clay
AM-6	89.34	702.39	683.11	19.28	3.1%	1	clay (g/L)
	5.3E+02	4.3E+03	4.2E+03	8.4E+01	2.2%		
	Post-test total mass of fines			84 g		2.0E-02	
	Mass of fines injected			181 g			
				46.3%			

1.06				181 g	
90.0	123.0	129.7	175.1	181 L	
372	510	538	730	753	
109.7	149.8	157.9	213.2	219.9	
119.5	119.5	117.5	119	119	
30	30	30	30	30	
15	15	15	15	15	
55	55	55	55	55	
29.7	30.2	30.3	30.3	30.4	
28.8	28.9	28.9	29.0	29.1	
28.5	28.6	28.6	28.7	28.8	
27.4	27.6	27.6	27.5	27.6	
28.0	28.0	28.0	28.0	28.0	
223	302	332	429	433	
3.98E-06	3.98E-06	3.92E-06	3.97E-06	3.97E-06	
0.13	0.19	0.20	0.18	0.18	
0.10	0.12	0.13	0.13	0.13	
0.16	0.15	0.15	0.18	0.17	
0.03	0.03	0.04	0.04	0.04	
3E-03	2E-03	2E-03	2E-03	2E-03	
4E-03	3E-03	3E-03	3E-03	3E-03	
2E-03	3E-03	3E-03	2E-03	2E-03	
1E-02	1E-02	1E-02	1E-02	9E-03	
0.84	0.58	0.53	0.60	0.60	
0.90	0.78	0.72	0.72	0.72	
0.87	0.91	0.90	0.76	0.80	
1.21	1.21	0.99	1.00	0.86	